Chapter 4
Airfoil and Wing/Tail Geometry Selection

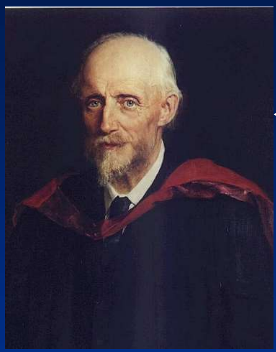
This Section

- Non-dimensional aerodynamic force and moment coefficients
- Wing section and planform
- Spanwise wing loading
- Winglets
- Wing location
- Tail location
- Initial tail sizing

Where are we now?

- Defined aircraft requirements
- Made a guess as to cruise L/D
- Made a guess as to cruise sfc
- Calculated estimate of MTOGW (W_{TO}) and W_E

Force Ratios in Aerodynamics



By John Collier - Copied from johnbyrne.fireflyinternet.co.uk. Cropped photo of a painting of Osborne Reynolds painted in 1904 by John Collier., Public Domain,
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Osborne Reynolds

Reynolds Number:

$$R_e\left(\text{or}\,R_N\right)=\frac{\text{Inertia Force}}{\text{Viscous Force}}=\left(\frac{\rho}{\mu}\right)V\,l=\frac{V\,l}{\nu}$$

where

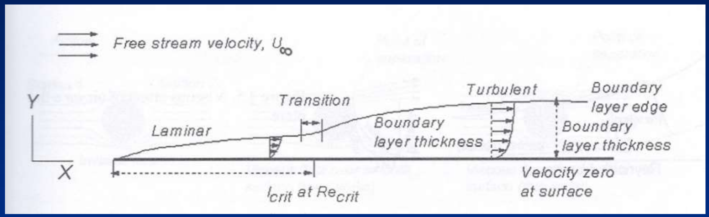
$\rho =$ air density

$\mu =$ absolute (or dynamic) viscosity

$\nu =$ kinematic viscosity

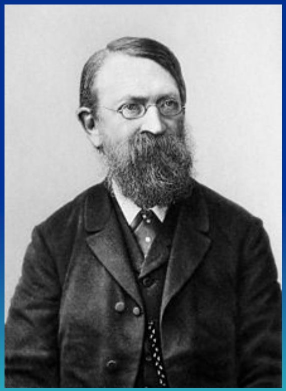
$V =$ free stream velocity

$l =$ representative length



Source: Kundu

Ernst Mach



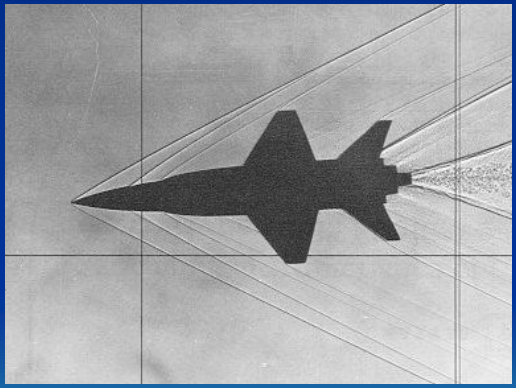
https://en.wikipedia.org/wiki/Ernst_Mach#/media/File:Ernst_Mach_01.jpg

Mach Number:

$$M=\frac{\text{Inertia Forces}}{\text{Elastic Forces}}=\frac{V}{a}$$

where

$a =$ ambient speed of sound in air



Source: www.centenialofflight.gov

Aerodynamic Forces and Moments in Plane of Symmetry

Lift Coefficient $C_L = \dfrac{L}{\left(\frac{1}{2}\right)\rho V^2 S}$

Drag Coefficient $C_D = \dfrac{D}{\left(\frac{1}{2}\right)\rho V^2 S}$

Pitching Moment Coefficient $C_M = \dfrac{M}{\left(\frac{1}{2}\right)\rho V^2 \bar{c}\, S}$

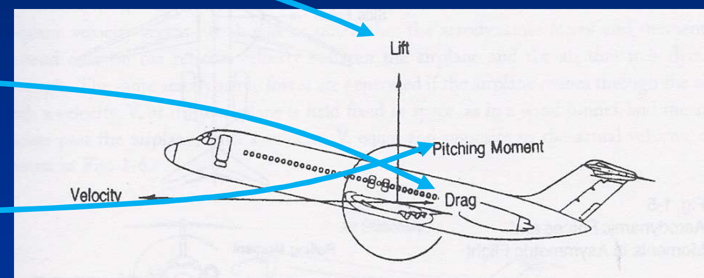
where

$\rho =$ local air density

$V =$ true airspeed

$\bar{c} =$ mean aerodynamic chord

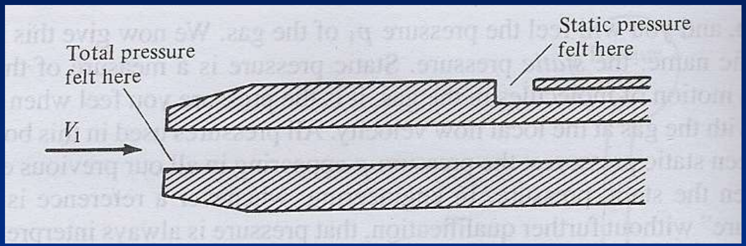
$S =$ reference wing area



Source: Schaufele

By definition, lift is perpendicular to velocity vector and drag is along velocity vector. Pitching moment is positive nose-up.

Dynamic Pressure



Source: Anderson

Aerodynamic pressures are related by

$p_t = p_s + q$

where

p_t = total pressure

p_s = static pressure

q = dynamic pressure: measure of the air pressure due to motion of the aircraft through the air

We can write

$$C_L = \frac{L}{q\,S}$$

$$C_D = \frac{D}{q\,S}$$

$$C_M = \frac{M}{q\,\bar{c}\,S}$$

where

dynamic pressure $q = \left(\frac{1}{2}\right)\rho V^2$

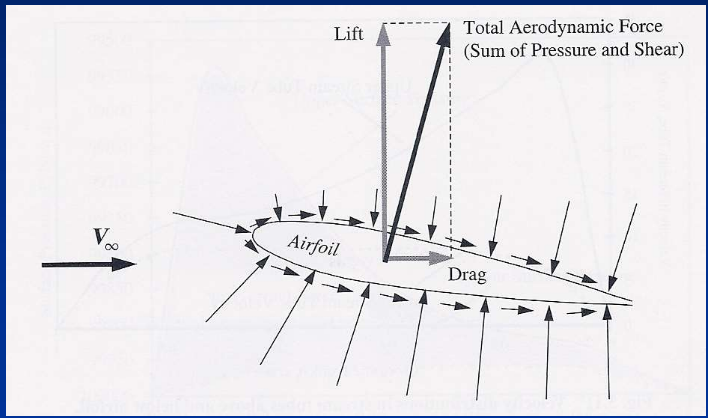
Forces and Moments on a 2-D Airfoil

On a two-dimensional section, forces and moments per unit width

$$C_l = \frac{L}{\left(\frac{1}{2}\right)\rho V^2 c}$$

$$C_d = \frac{D}{\left(\frac{1}{2}\right)\rho V^2 c}$$

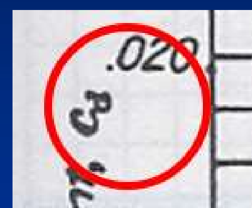
$$C_m = \frac{M}{\left(\frac{1}{2}\right)\rho V^2 c^2}$$

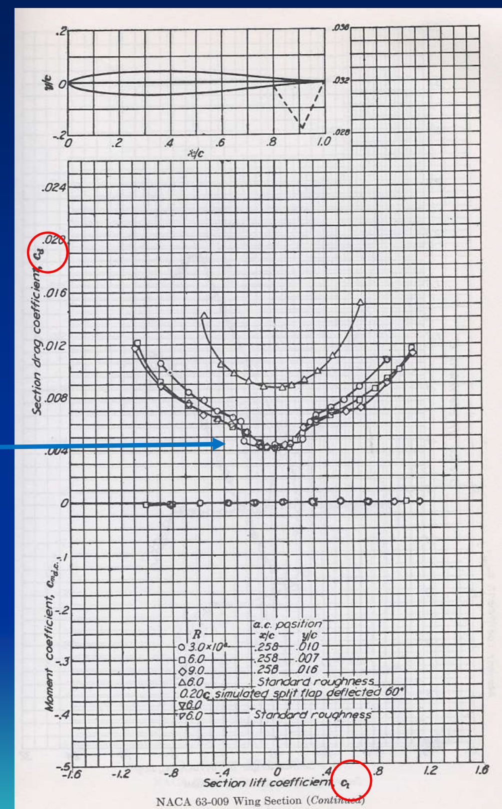


Source: Schaufele

Example of Forces on a 2-D Airfoil

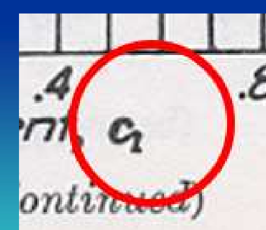
- Drag is primarily due to increased shear forces
- <u>No</u> induced drag
- Note drag bucket near α = +/-2^0





Source: Abbott & Von Doenhoff

Lower case suffixes imply section force coefficients



Lateral-Directional Forces and Moments

Yawing moment $C_n = \frac{N}{qbS}$

where

N = yawing moment

b = wingspan

Side force coefficient $C_y = \frac{Y}{qS}$

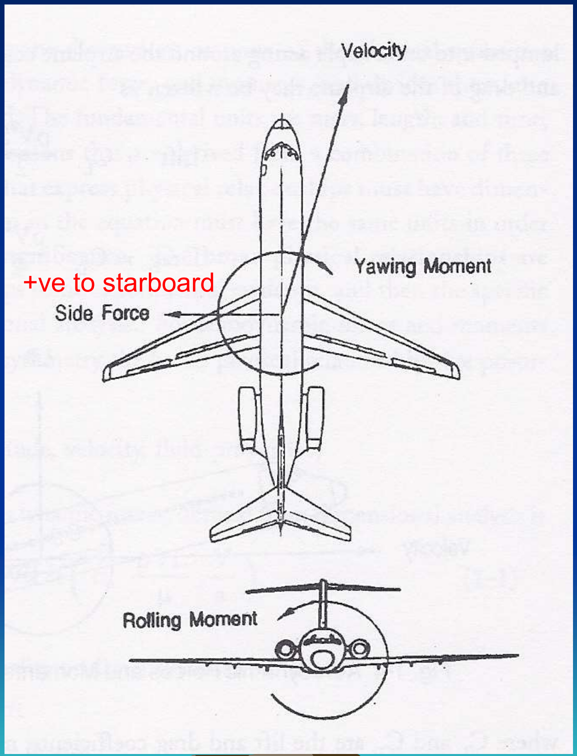
where

Y = side force (+ ve to starboard)

Rolling moment coefficient $C_l = \frac{L}{qbS}$

where

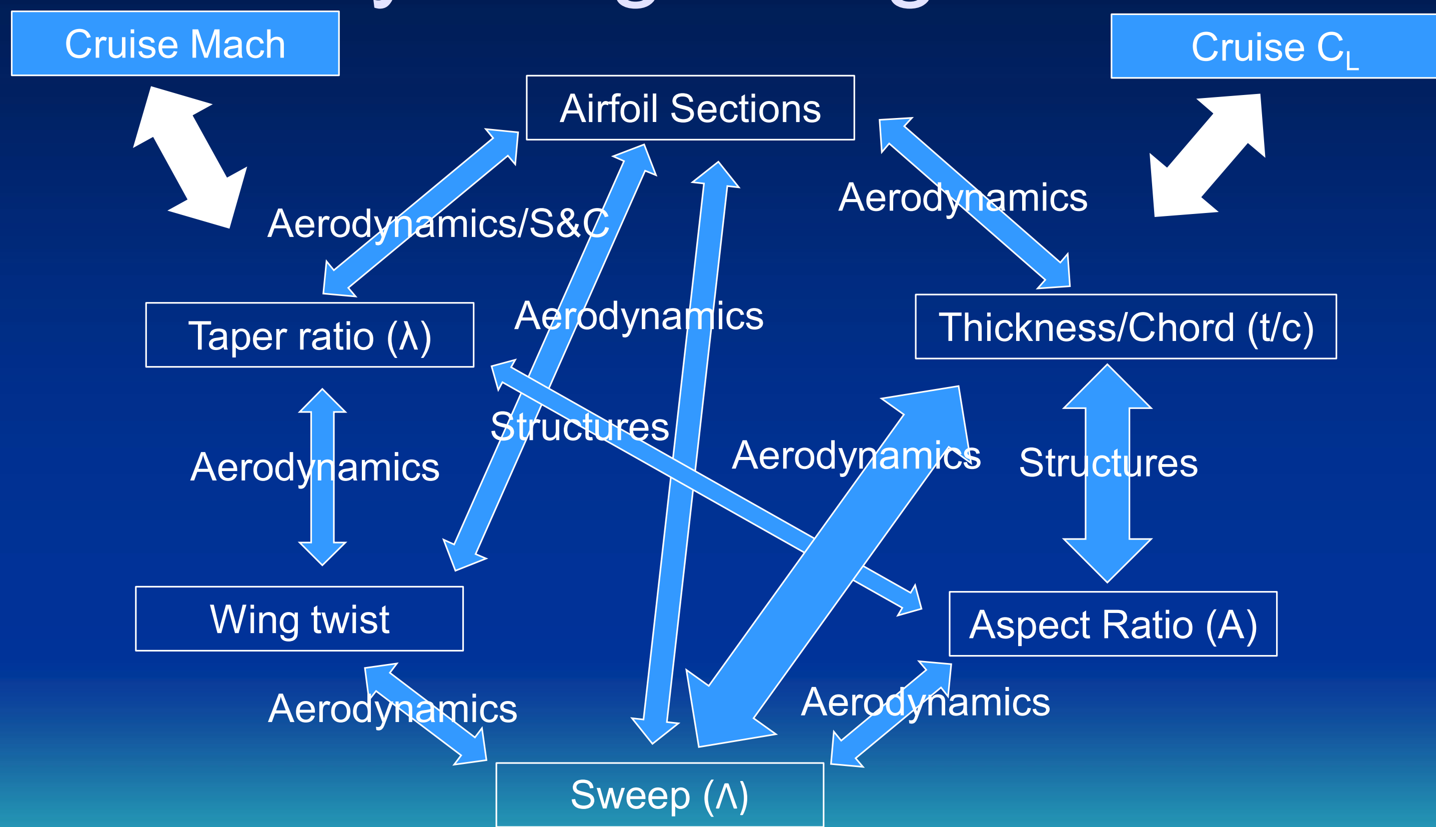
L = rolling moment (NOT lift force)



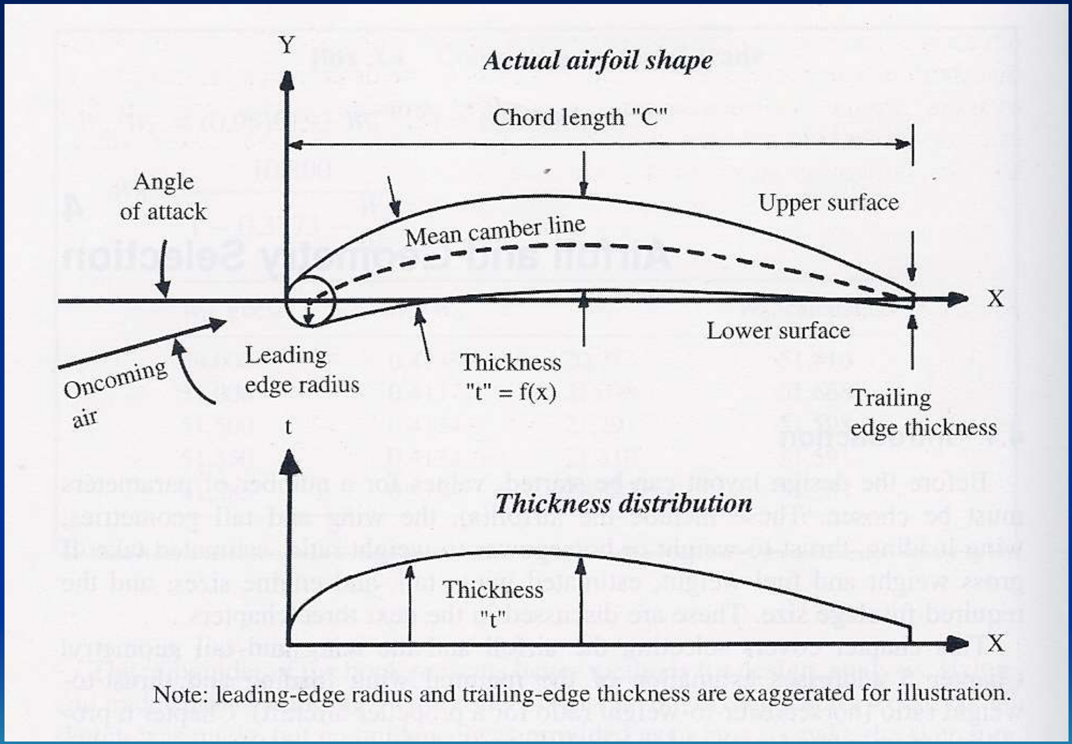
Source: Schaufele

Section 4.3
Wing Geometry

Primary Wing Design Variables



Airfoil Section Geometry



Source: Raymer

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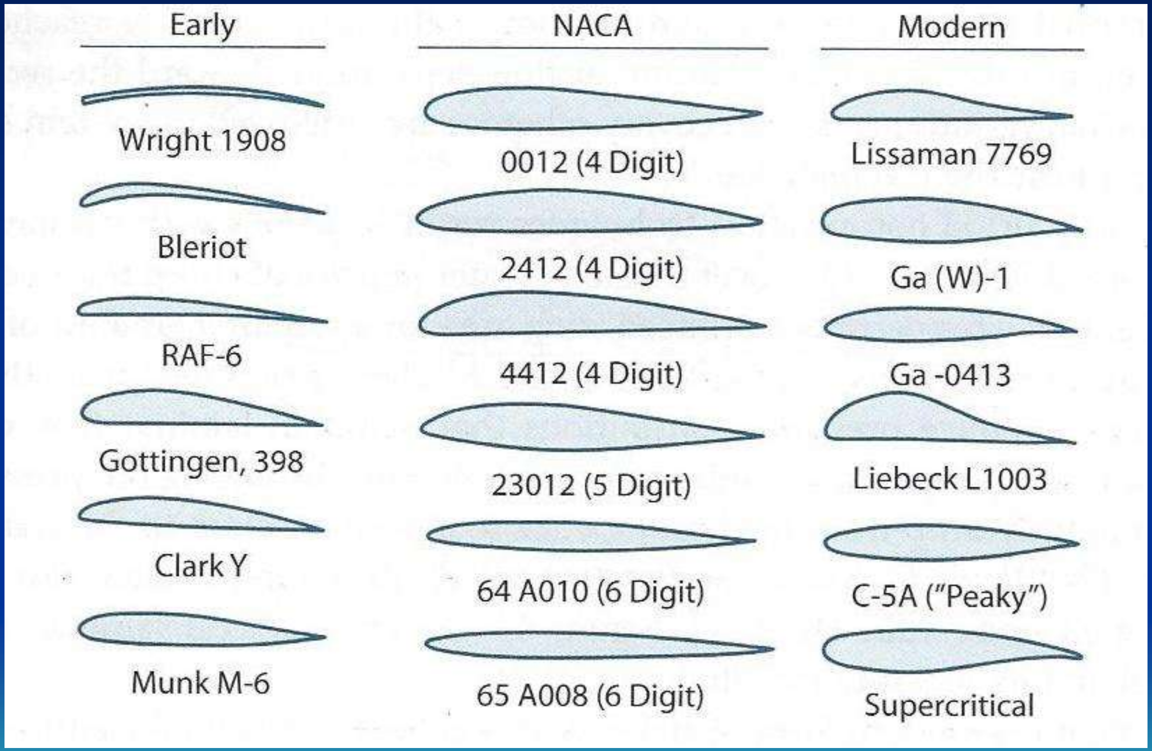
Airfoil Sections – Infinite Choice



Mostly proprietary

Source:Raymer

Airfoil Section Numbering

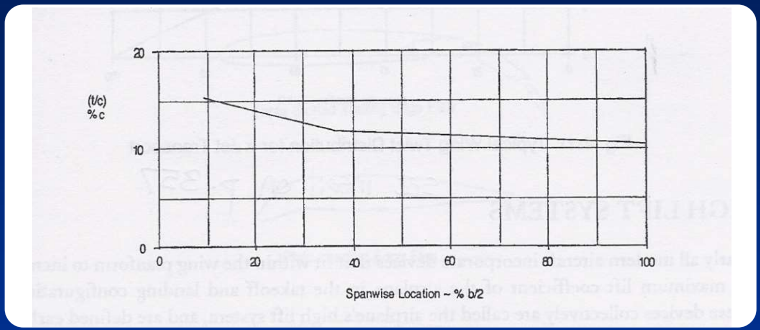
- NACA 4415
  - 4 = maximum camber of the mean line is 0.04c
  - 4 = position of the maximum camber is 0.4c
  - 15 = maximum thickness is 0.15c
- NACA 23012
  - 2 = maximum camber of the mean line is approximately 0.02c (design lift coefficient is 0.15 X the first digit of the series
  - 30 = position of the maximum camber is at 0.30/2 = 0.15c
  - 12 = maximum thickness is at 0.12c

Airfoil Section Numbering

- NACA 65_3-421
  - 6 = series designation
  - 5 = minimum pressure is at 0.5c
  - 3 = drag coefficient is near its minimum values over of a range of lift coefficients of 0.3 above and below the design lift coefficient
  - 4 = design lift coefficient is 0.4
  - 21 = maximum thickness is 0.21c

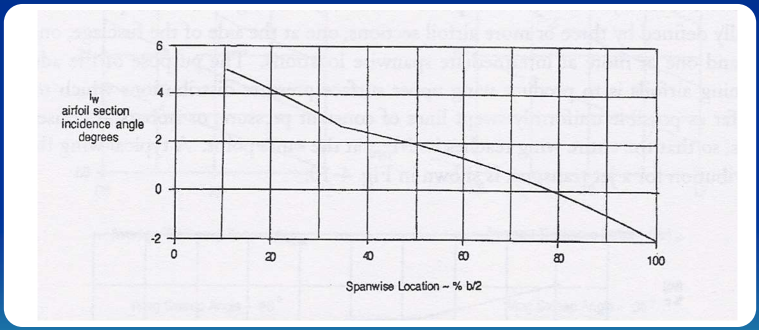
Typical Thickness Distribution and Twist

Increased wing root t/c improves structural efficiency where wing bending is greatest, and provides space for main landing gear



Source: Schaufele

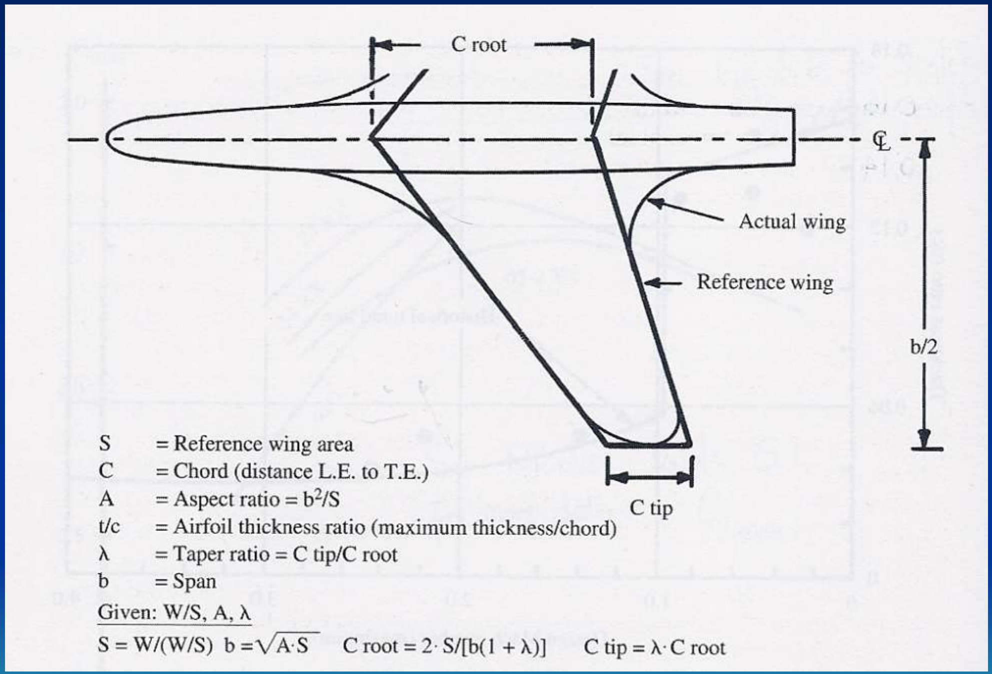
Wing twist reduces tendency for tip to stall first, and may also make spanwise lift distribution closer to elliptical at a given C_L



Source: Schaufele

Wing Planform

- Reference wing area (S_{ref}) is usually the area of trapezoid that approximates the wing planform, except at Boeing which includes some of yehudi
- Airbus uses modified gross wing area



Source: Raymer

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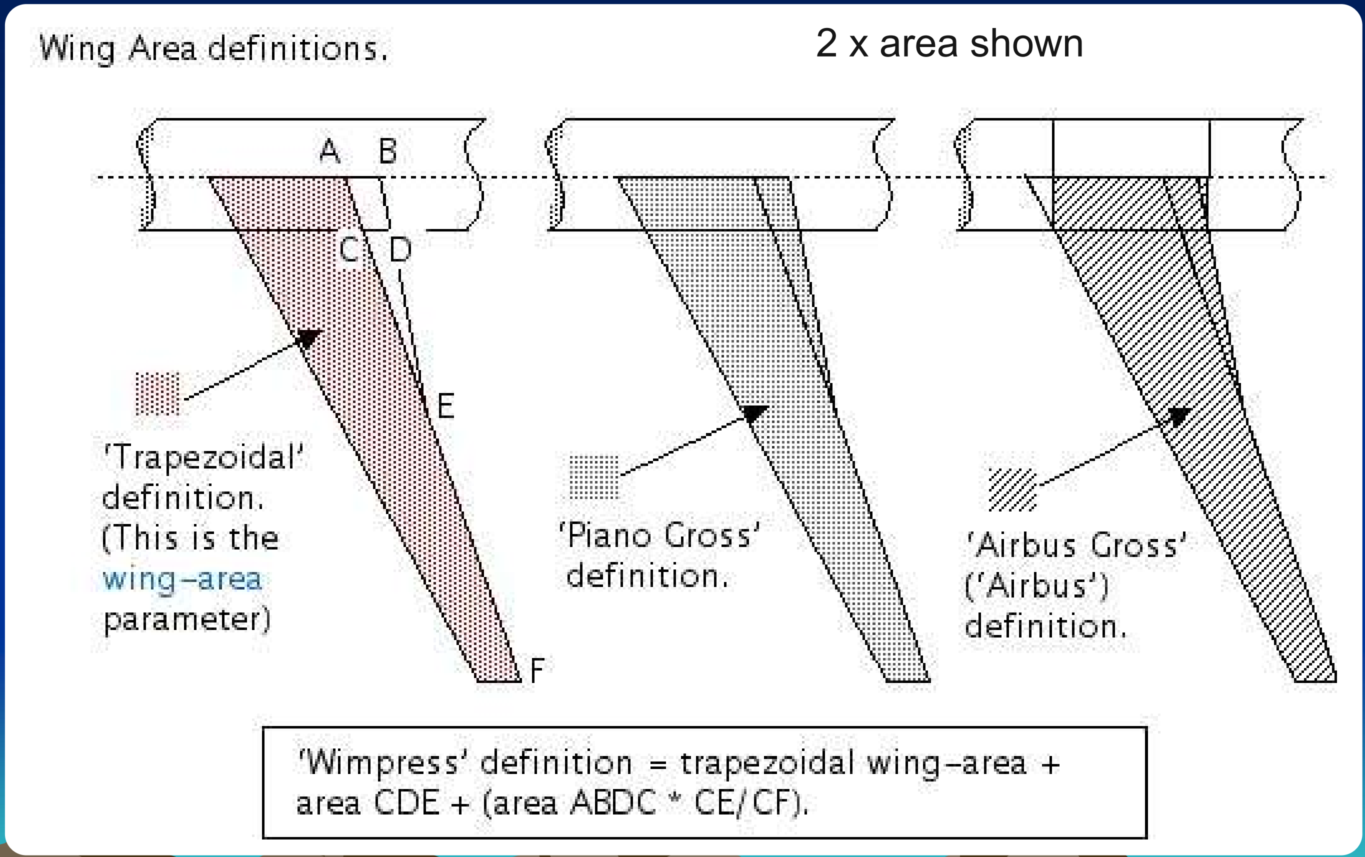
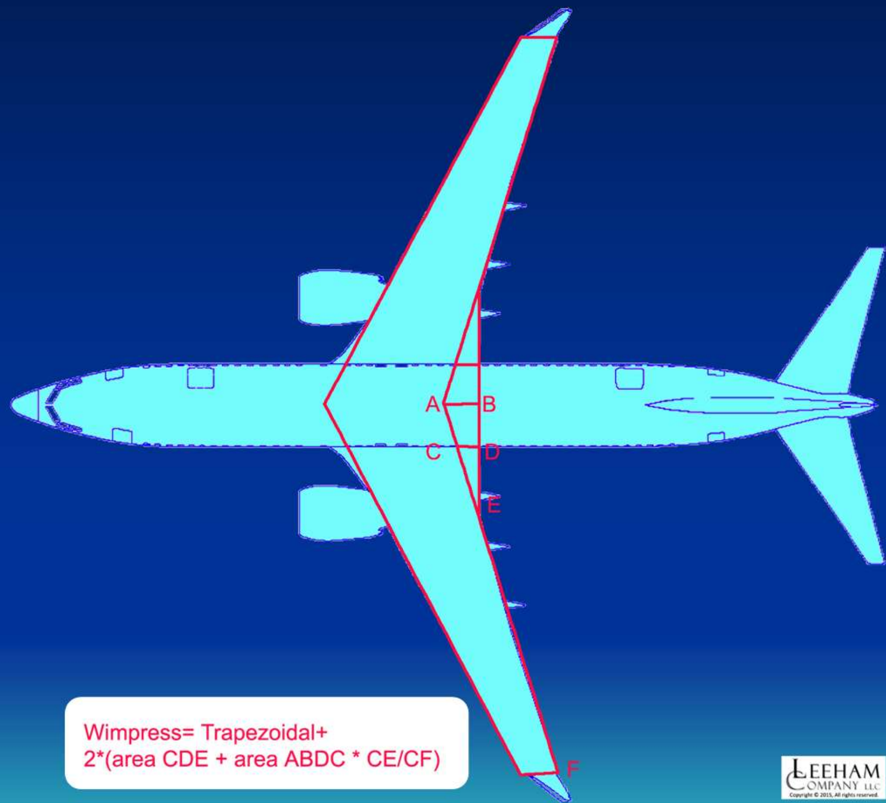
Wing Reference Area Definitions



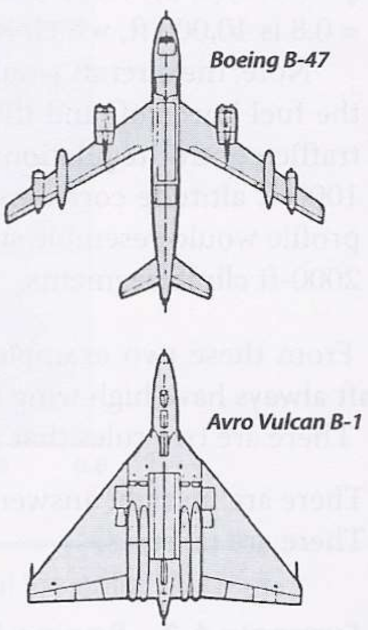
Source: http://www.lissys.demon.co.uk/

Boeing Wing Reference Area



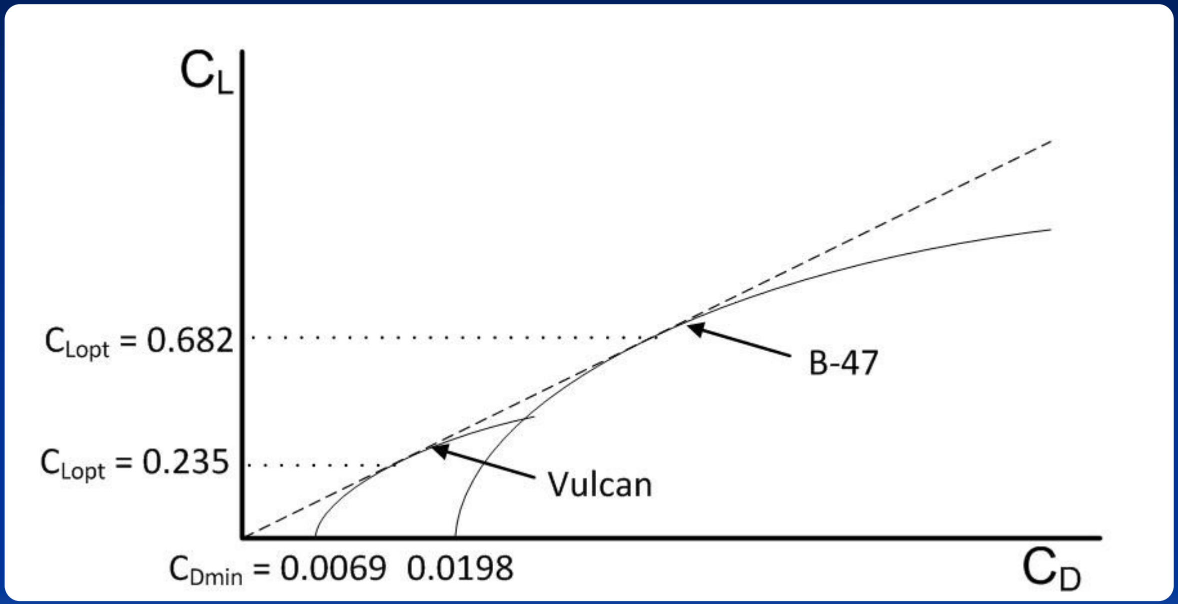
Comparison between B-47 and Avro Vulcan Aerodynamic Characteristics

	Boeing B-47	Avro Vulcan
Wing Area (ft^2)	1430	3446
Total Wetted Area (ft^2)	11,300	9,500
Span (ft)	116	99
Wing Loading (lb/ft^2)	140	43
Span Loading (lb/ft)	1750	1520
Aspect Ratio	9.43	2.84
C_{Dmin}	0.0198	0.0069
$K = 1/(\pi AR e)$	0.0425	0.125
Value of e	0.8	0.9
Max L/D	17.25	17.0
C_{Lopt}	0.682	0.235
Max Cruise C_L	0.48	0.167
$C_{Dmin} S_{ref}$	28.3	23.8
Wetted Area / S_{ref}	7.9	2.8



Source: Raymer

B-47 and Avro Vulcan Drag Polar Comparison



Speeds:

- Vulcan M_{cruise} = 0.947 M_{max} = 0.977
- B-47 M_{combat} = 0.847 M_{max} = 0.910

Wing Planform

Given parameters:

$Reference\left(weight\ at\ block\ release\right) = W_o$

$Wing\ loading = \frac{W}{S}$

$Aspect\ ratio = A$

$Taper\ ratio = \lambda$

$Sweep\ of\ quarter\ chord = \Lambda_{\frac{c}{4}}$

Reference area $S = \frac{W_o}{\left(\frac{w}{s}\right)}$

Span $b = \sqrt{AS}$

Root chord $c_{root} = \frac{2b}{A(1+\lambda)} = \frac{2}{1+\lambda}\sqrt{\frac{S}{A}}$

MAC $\bar{c} = \frac{2}{3} c_{root} \frac{1+\lambda+\lambda^2}{1+\lambda}$

$= \frac{4}{3} \frac{\left(1+\lambda+\lambda^2\right)}{(1+\lambda)^2} \sqrt{\frac{S}{A}}$

y location of MAC $\bar{y} = \frac{b}{6} \frac{(1+2\lambda)}{(1+\lambda)}$

Sweep of Arbitrary Fraction of Chord

General relationship between leading edge sweep and sweep at arbitrary fraction of chord:

$$\tan\Lambda_{xc} = \tan\Lambda_{LE} - 4x\,\frac{1-\lambda}{A(1+\lambda)}$$

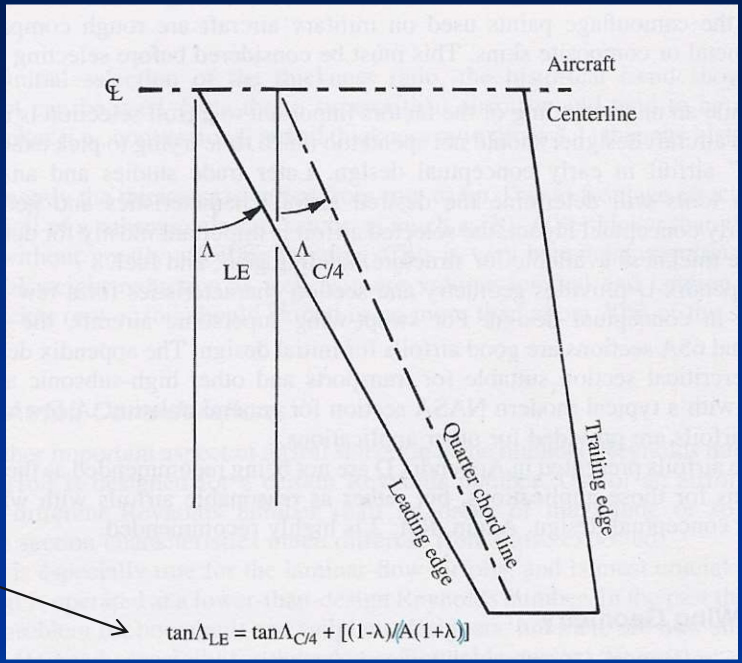
where x is fraction of chord, c

E.g.

$$\tan\Lambda_{\frac{c}{4}} = \tan\Lambda_{LE} - \frac{1-\lambda}{A(1+\lambda)}$$

Or

$$\tan\Lambda_{\frac{c}{2}} = \tan\Lambda_{LE} - 2\,\frac{1-\lambda}{A(1+\lambda)}$$



Source: Raymer

Sweep is normally defined by by $\Lambda_{c/4}$, but for supercritical wing L/D calculations, it may be defined by $\Lambda_{c/2}$

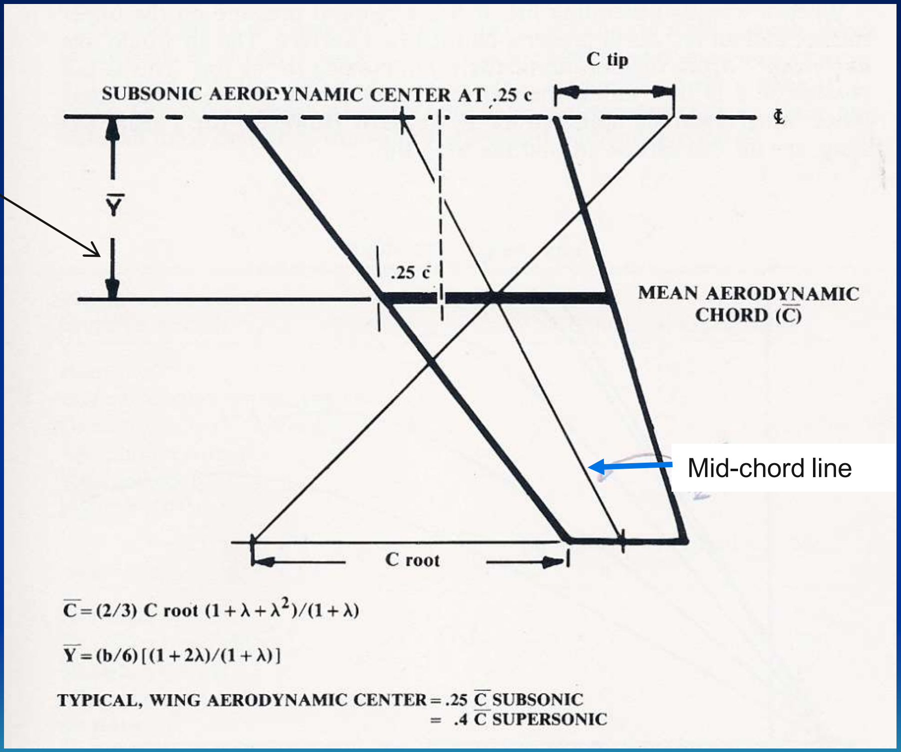
Mean Aerodynamic Chord

Two ways to determine MAC

1. Graphical
2. Algebraic

$$\bar{c} = \left(\frac{2}{3}\right) c_{root} \frac{1 + \lambda + \lambda^2}{1 + \lambda}$$

$$\bar{y} = \left(\frac{b}{6}\right) \frac{1 + 2\lambda}{1 + \lambda}$$



Source: Raymer

MAC of Cranked Wing

For a cranked wing planform

equivalent mac is $\bar{c} = \dfrac{\bar{c}_1 S_1 + \bar{c}_2 S_2}{S_1 + S_2}$

Location is defined by

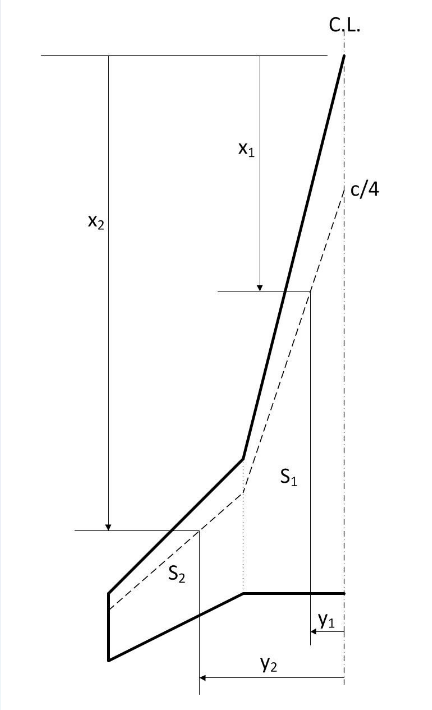
$$\bar{x} = \frac{x_1 S_1 + x_2 S_2}{S_1 + S_2}$$

$$\bar{y} = \frac{y_1 S_1 + y_2 S_2}{S_1 + S_2}$$

where

$\bar{x}$ = x location of $\dfrac{c}{4}$ for equivalent mac

$\bar{y}$ = y location of equivalent mac

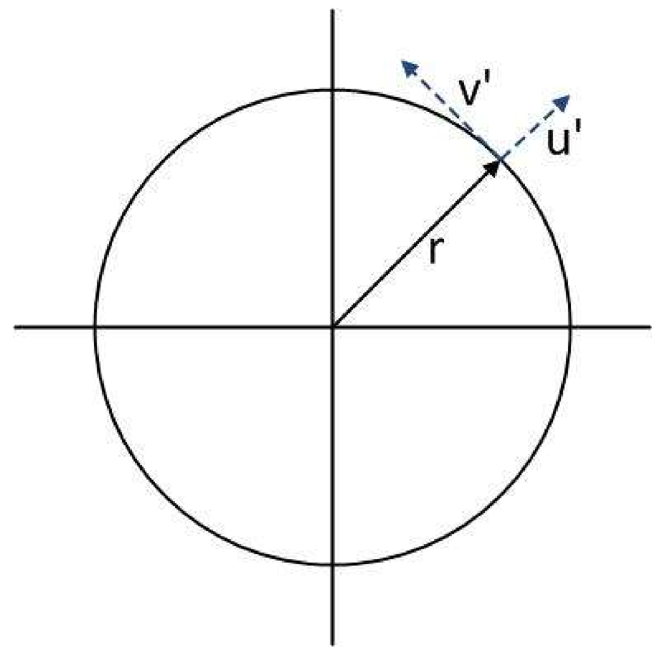


Strength of Free Vortex

*S*trength of free vortex, $\Gamma = v' 2\pi r$

Circumferential component of velocity, $v' = \dfrac{\Gamma}{2\pi r}$

Radial component of velocity , $u' = 0$



Distribution of Circulation

Put spanwise location, y, in terms of θ where

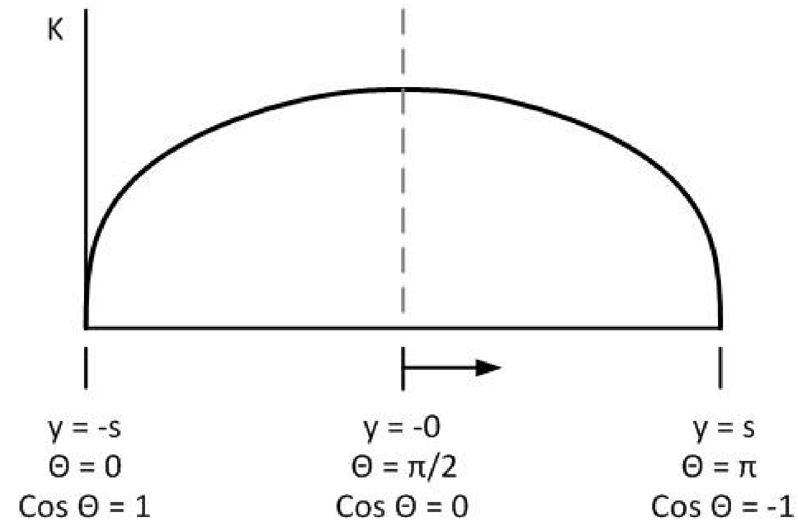
$$y = -s\cos\theta$$

Define spanwise distribution of circulation, Γ, as a Fourier series

$$\Gamma = -U\,4\,s\sum_{n=1}^{\infty} A_n \sin n\theta$$

Total lift

$$L = -\int_{-s}^{+s} \rho U \Gamma dy$$



Distribution of Circulation for Minimum D_i

All terms in Fourier series contribute to drag

so for minimum induced drag $A_2 = A_3 = A_4 = \ldots = 0$

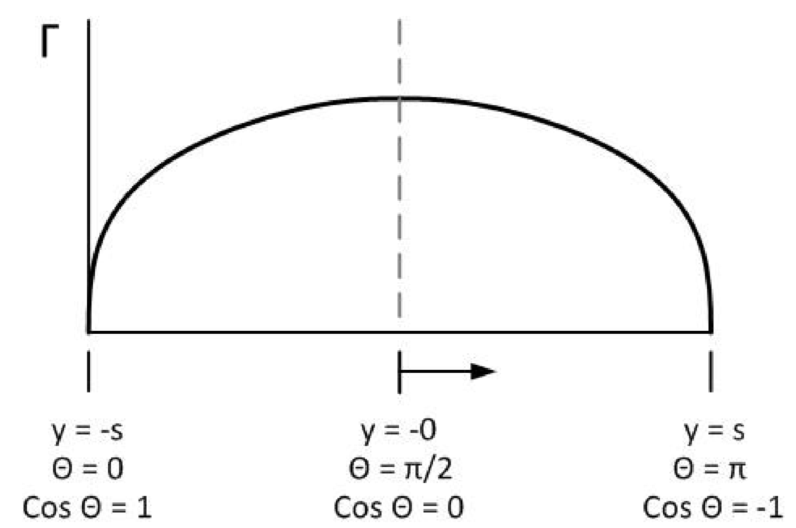
$$\Gamma = -4\,U\,s\,A_1 \sin\theta$$

$$\cos\theta = \frac{y}{s} \quad \text{so} \quad \sin\theta = \sqrt{1 - \frac{y^2}{s^2}}$$

$$\Gamma = -4\,U\,s\,A_1 \sqrt{1 - \frac{y^2}{s^2}}$$

$$\left(\frac{\Gamma}{-4\,U\,s\,A_1}\right)^2 + \left(\frac{y}{s}\right)^2 = 1$$

i.e. spanwise elliptic distribution of Γ



Planform with Minimum Induced Drag

Elliptical planform has minimum induced drag at all values of C_L

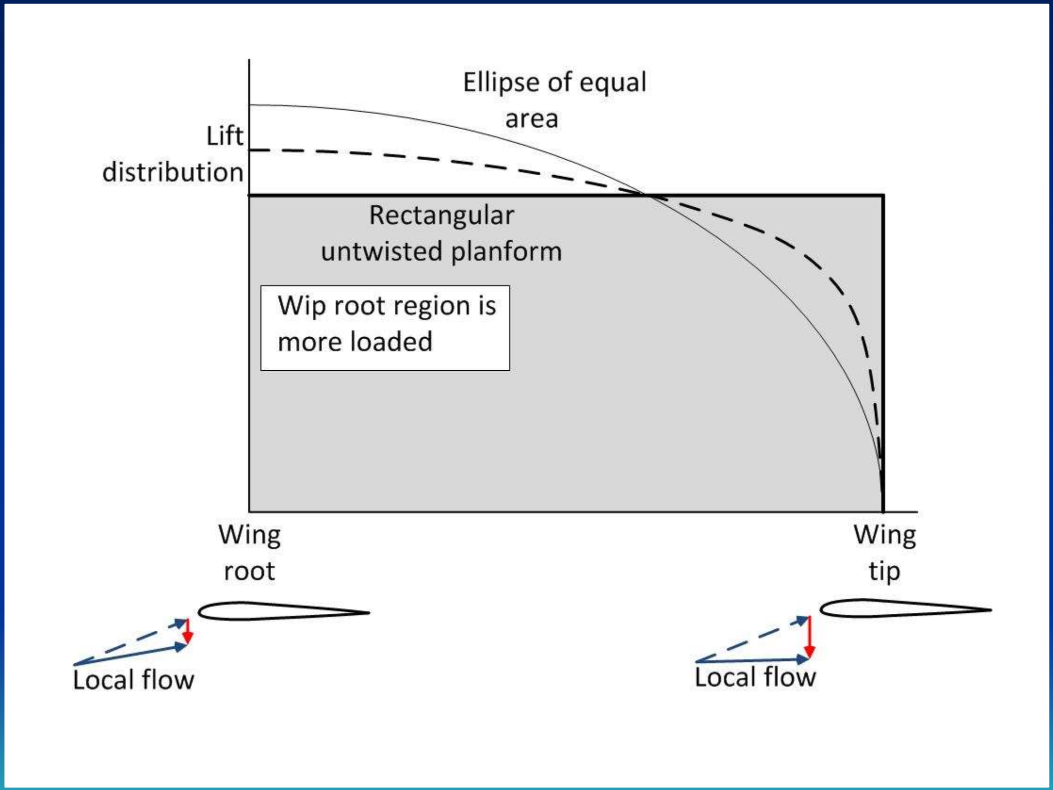
Trends in Wing Aspect Ratio and Taper Ratio

Aircraft Type	Aspect Ratio (AR)	Taper Ratio (λ)
Personal/Utility	5.0 – 8.0	0.6 – 1.0
Commuter Airliner	9.0 – 12.0	0.5 – 1.0
Regional Turboprop	11.0 – 12.8	0.4 – 0.6
Business Jet	5.0 – 8.8	0.4 – 0.6
Jet Transport	7.0 – 9.5	0.2 – 0.4
Military Fighter/Attack	2.4 – 5.0	0.2 – 0.5

Source: Schaufele

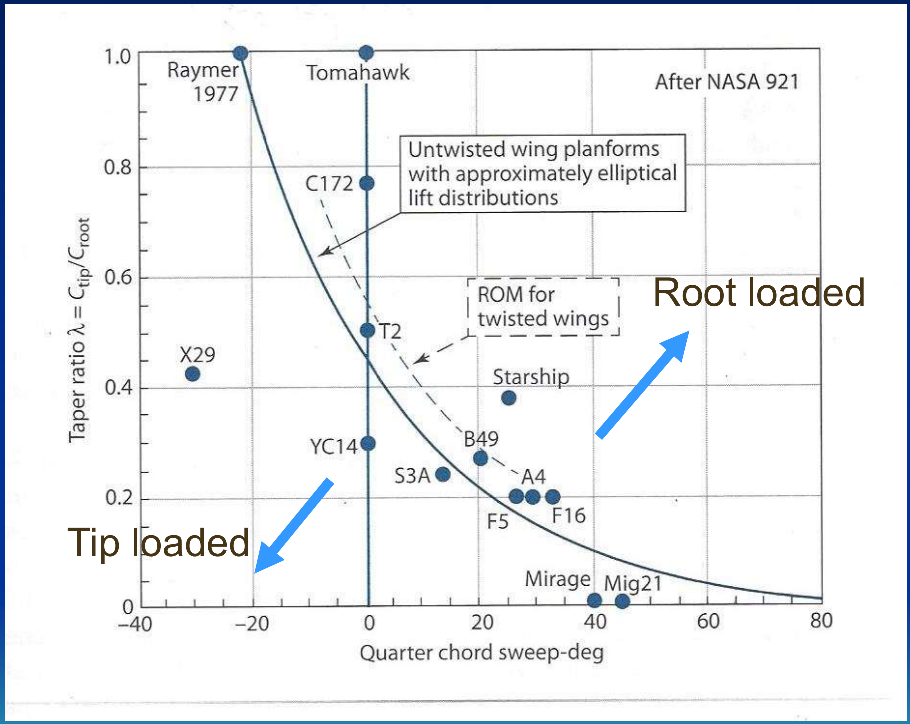
Schrenk's Approximation for Rectangular Planform

- Wing section aerodynamic load = (lift per unit span)/chord
- For an unswept, untwisted wing, lift distribution is represented by line midway between planform chord distribution and ellipse of equal area



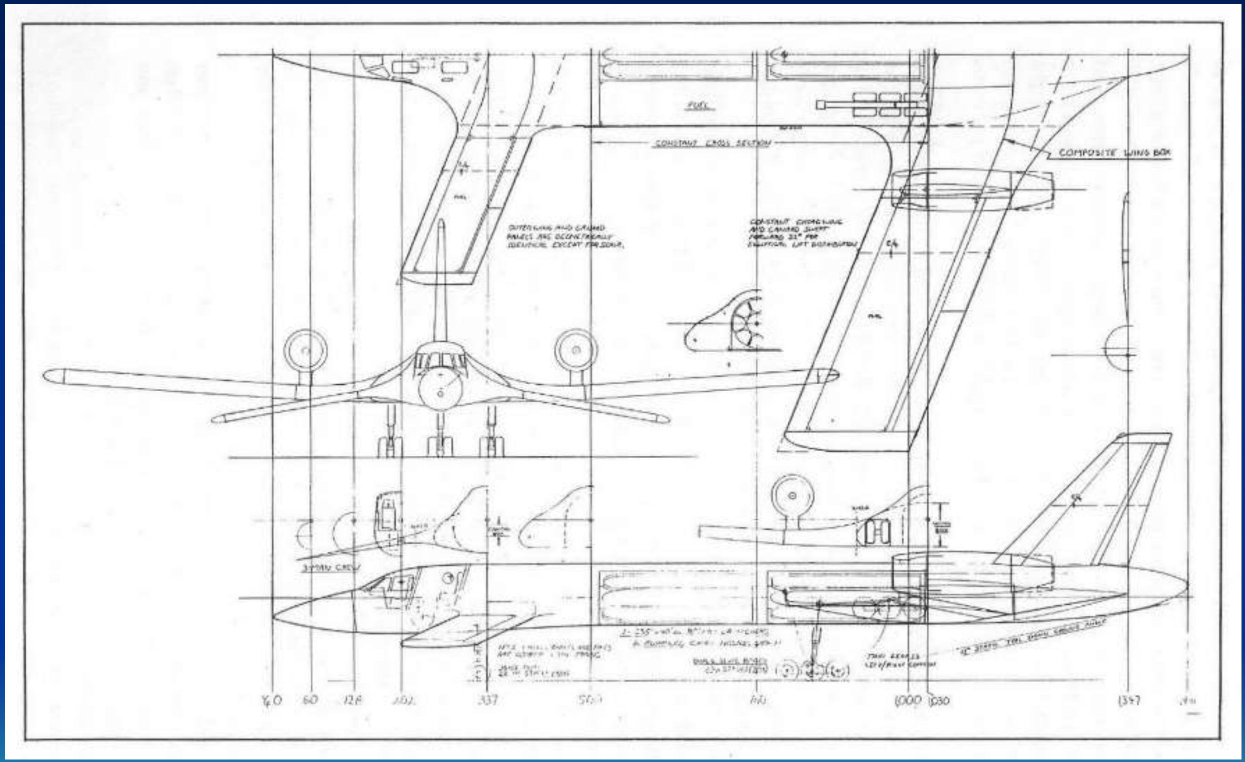
Downwash Effect is Accentuated

- Untapered, untwisted wing can have close to elliptical (minimum drag due to lift) lift distribution



Source: Raymer

If Wing is Swept Forward

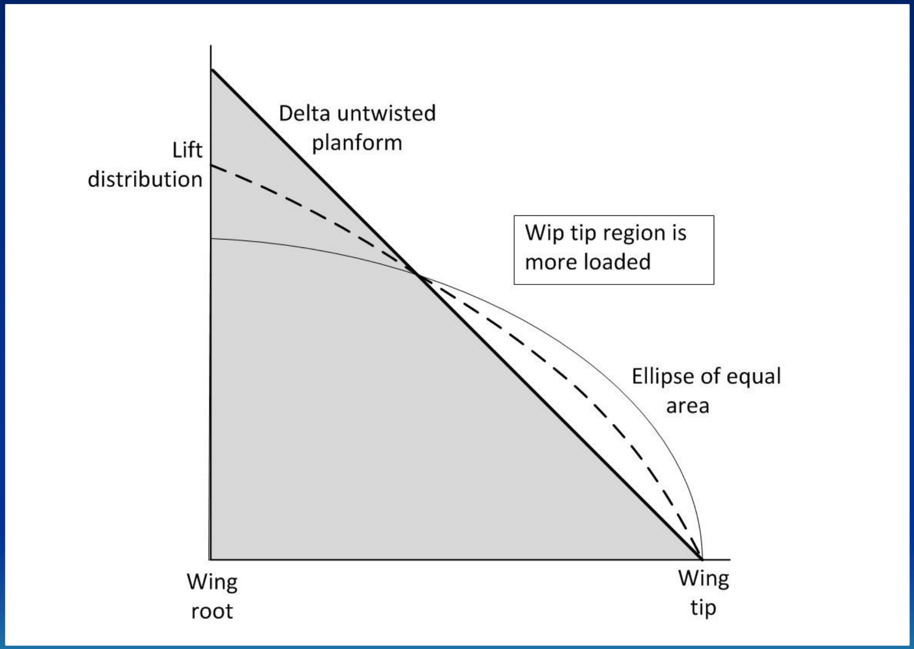


Source: Raymer

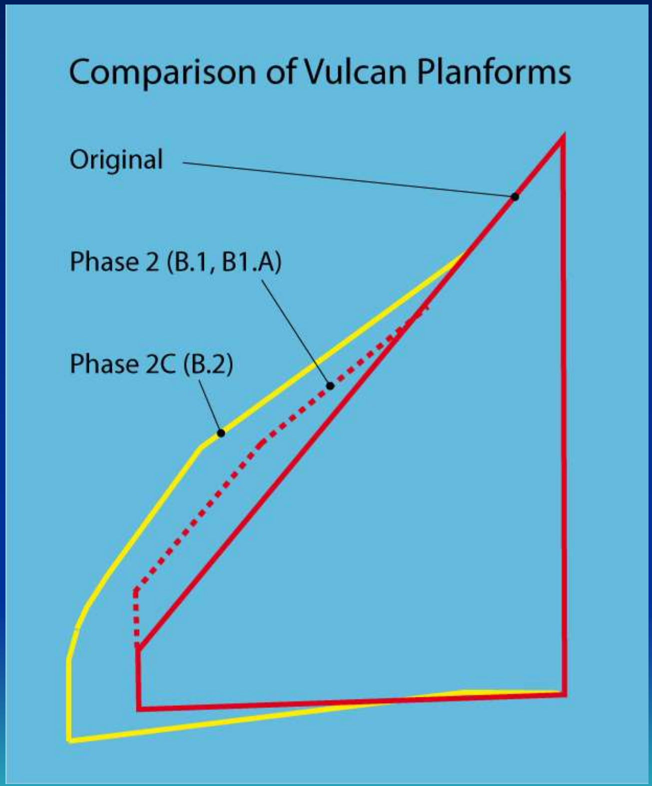
- Low-cost bomber concept

Schrenk's Rule for Delta Planform

- Likelihood of asymmetric stall
- Increased transonic drag



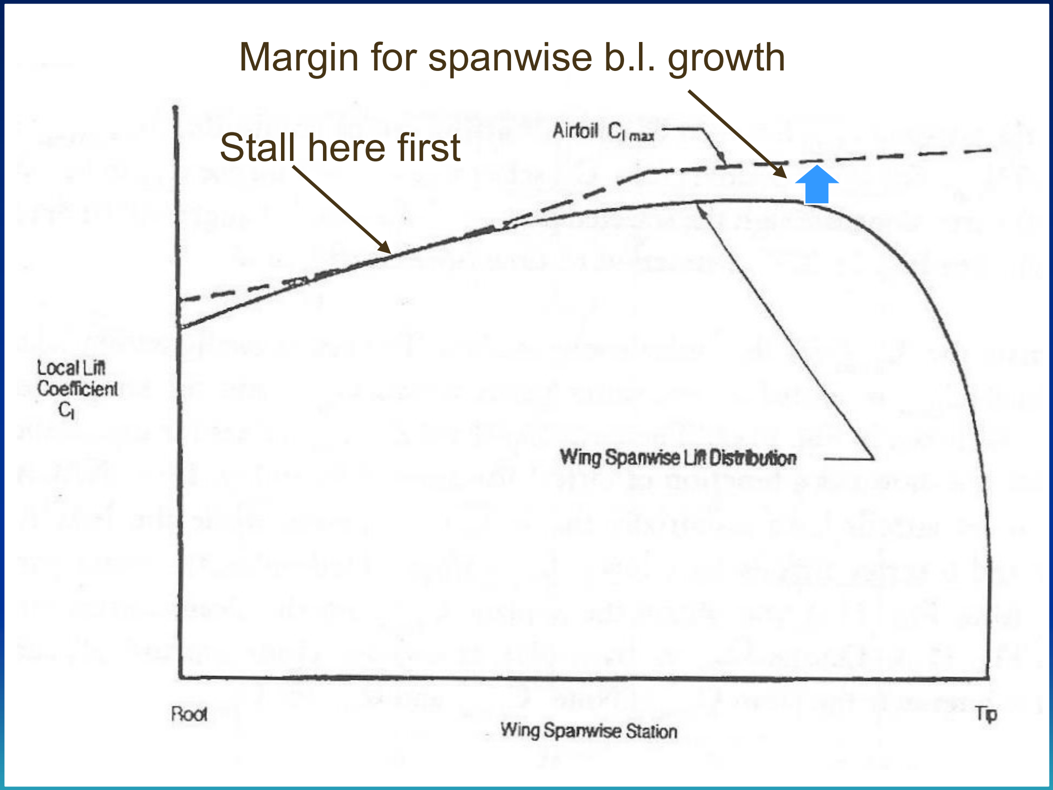
Development of Avro Vulcan Planform



Source (all images): commons.wikipedia.org

C_l as function of span for typical transport wing

- Ensure that wing stalls near root first
- Leave outboard margin for spanwise boundary layer migration



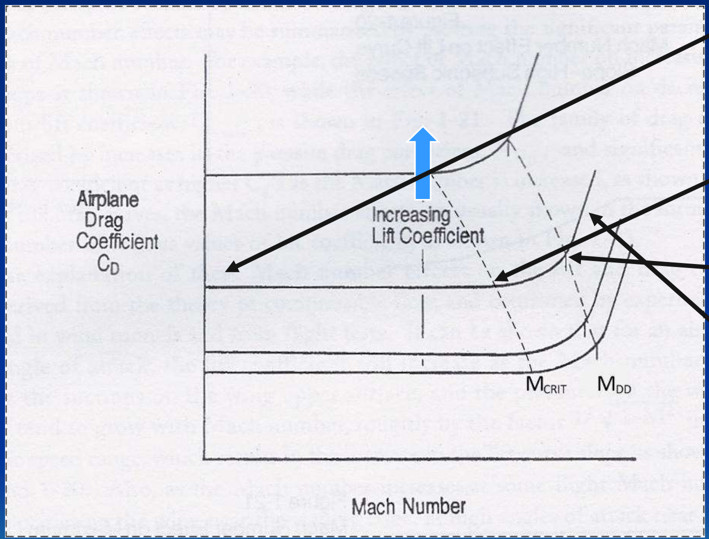
Source: Schaufele

SR-71 Leading Edge Washout

Source: commons.wikipedia.org

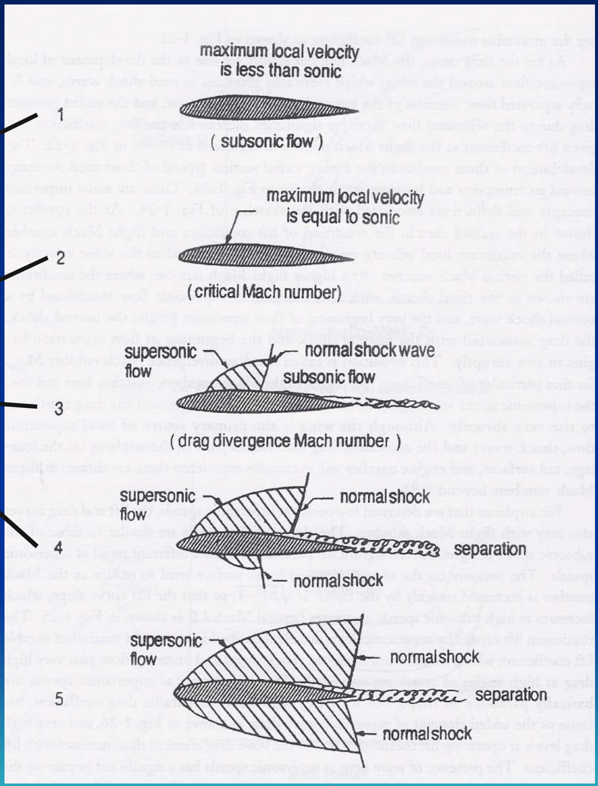
Flow Over Wing At Increasing Mach Number

M_{CRIT} and M_{DD} are a function of C_L (shown here), Λ and t/c



Source: Schaufele (modified)

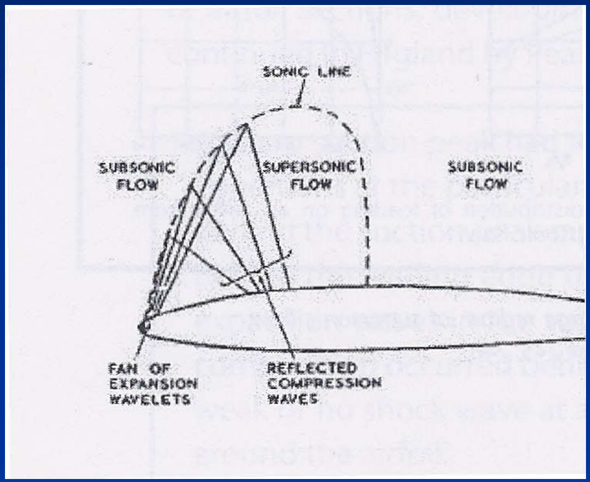
Note: this is not a supercritical airfoil section



Source: Schaufele

Flow within Supersonic Region

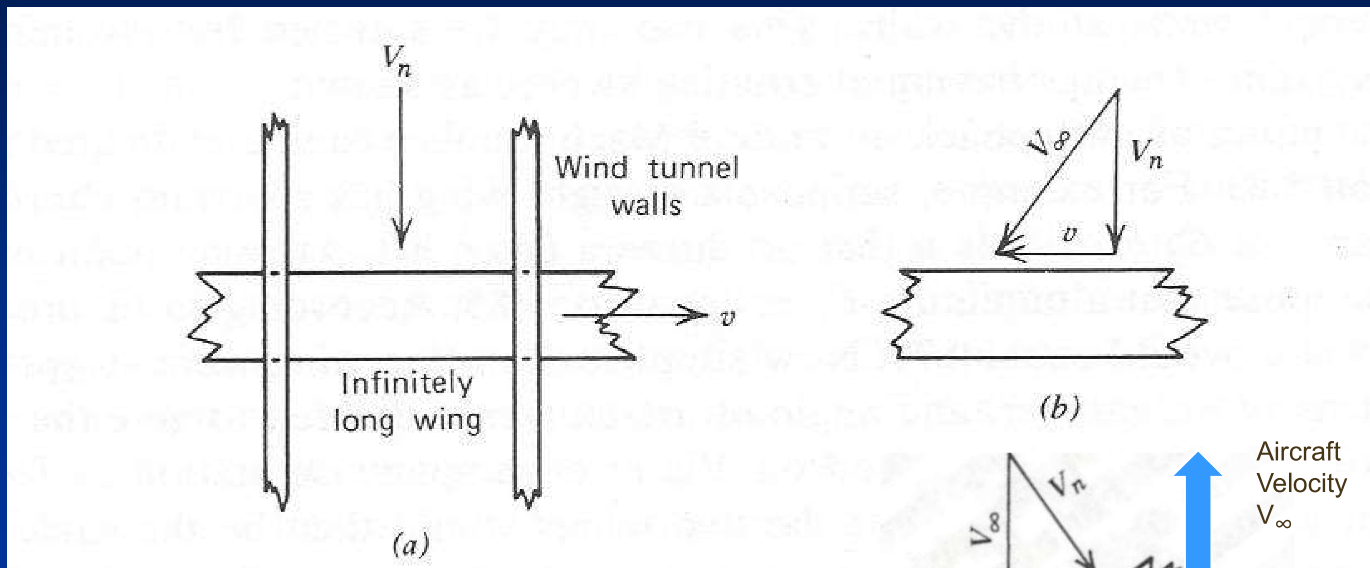
- System of expansion and compression waves exist within supersonic flow region

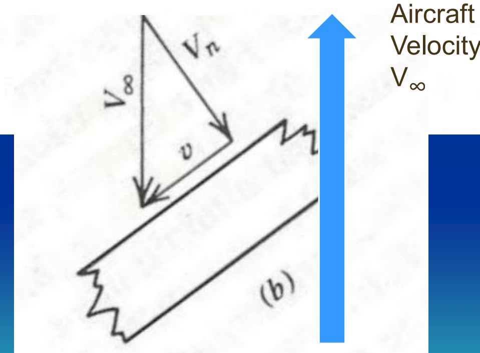


Source: Obert

Source: Schaufele

Swept wing thought experiment





Imagine an infinitely long wing moving at velocity *v* perpendicular to the wind tunnel flow, and that you are a bacterium sitting on the wing. Your apparent wind is V_∞

Source:McCormick

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1935 Volta Conference

- Dr. Adolf Busemann suggested swept wings for supersonic flight
- Arturo Crocco sketched out design of supersonic airplane on back of menu at dinner

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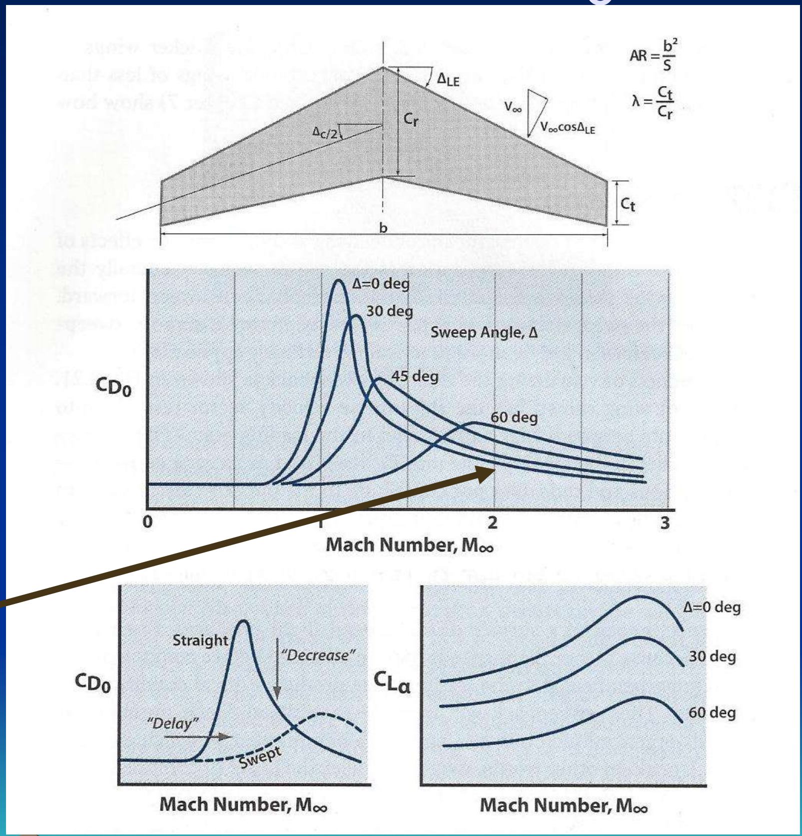
Effects of Sweep on C_{D_0}

- Sweep decreases and delays drag rise
- At M=2+, C_{D_o} increases with sweep



Source: Nicolai

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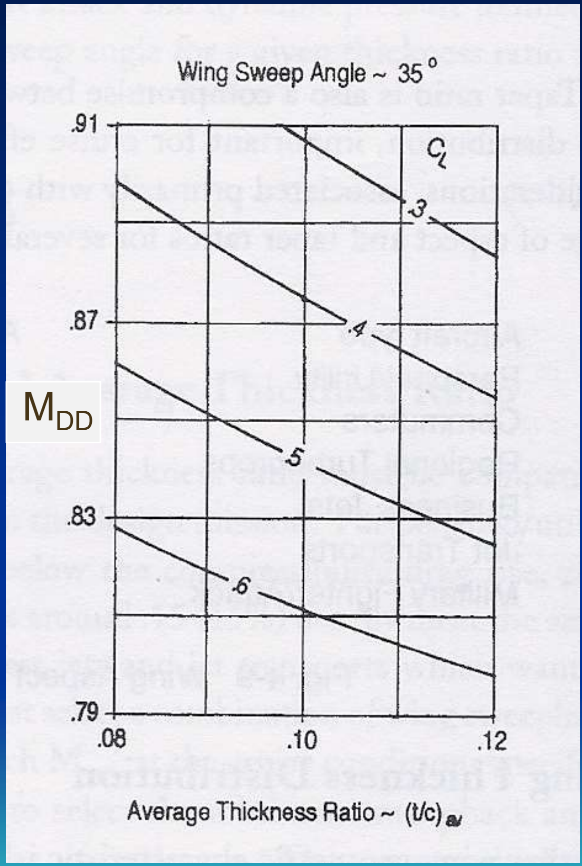
Wing Design Charts for Transonic Cruise Aircraft

- Average t/c is defined as

  Wing frontal area (untwisted)

  Wing planform area

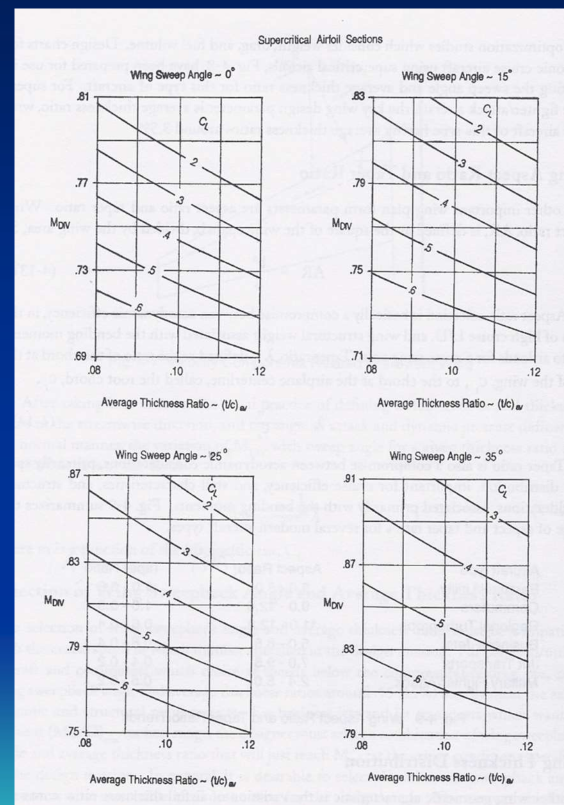
- Chart applies to supercritical airfoil sections with a given level of technology
- For given wing characteristics (sweep and average t/c) and cruise C_L, M_{DD} can be estimated
- Charts available for Λ = 0, 15, 25, 35 deg.



Source: Schaufele

Wing Design Charts for Transonic Cruise Aircraft

- For a given M_{DD} and cruise C_L, tradeoff exists between wing sweep (Λ) and t/c
- Evaluate tradeoff using detailed aircraft synthesis and sizing program



Source: Schaufele

Drag Divergence Mach Number (M_{DD})

Douglas definition more generally accepted

Very approximate

Definitions of Drag Divergence Mach Number

Boeing :

M_{DD} occurs when $C_D(@M_{DD}) - C_D(@M_{CRIT}) = 0.0020$

i.e. when the airplane is flying 20 counts into the drag rise .

Douglas :

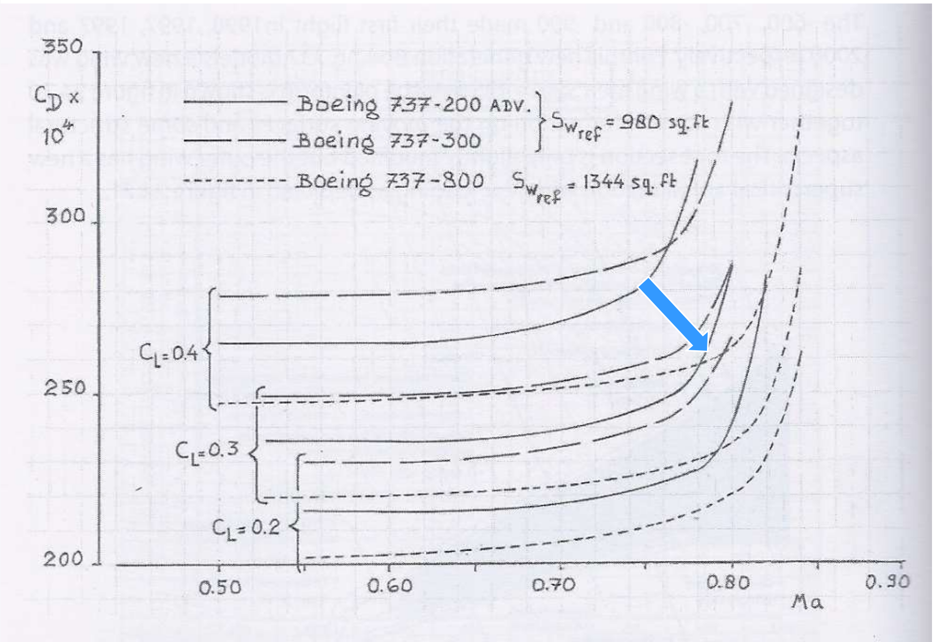
M_{DD} occurs when $\frac{dC_D}{dM} = 0.10$

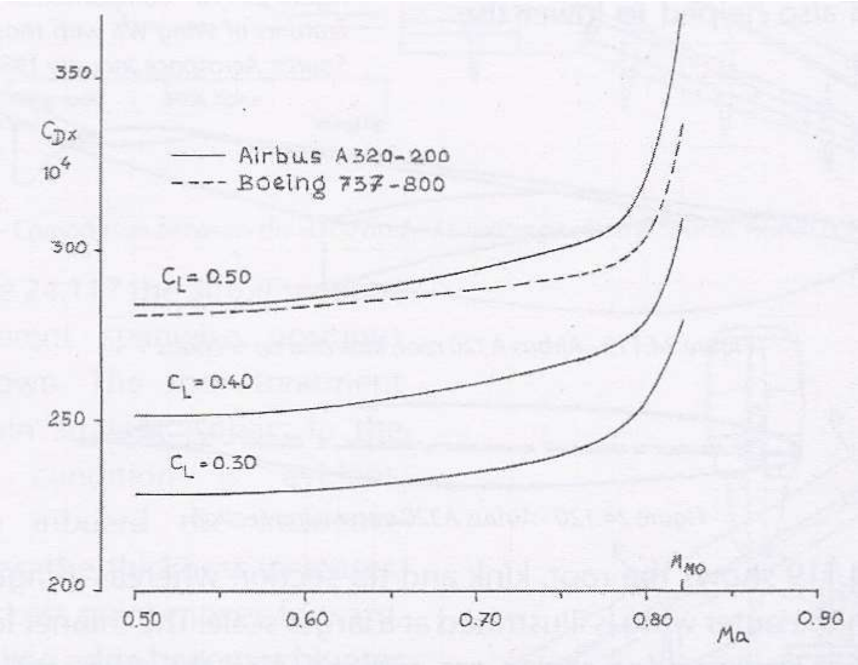
i.e. when the gradient of the drag rise curve is 0.10

Raymer suggests $M_{DD\,(Douglas)} \approx M_{DD\,(Boeing)} + 0.06$

(Note that one drag count is defined as $\Delta C_D = 0.0001$)

Tool for Comparing Wing Technology





- Airbus wing design not surpassed until 737NG series in 1997

Source: Obert

More Generalized Analysis Using Extended Korn Equation

$$\left(M_{dd}\right)_{Douglas} = \frac{\kappa_a}{\cos\left(\Lambda_{\frac{c}{2}}\right)} - \frac{\frac{t}{c}}{\cos^2\left(\Lambda_{\frac{c}{2}}\right)} - \frac{C_l}{\cos^3\left(\Lambda_{\frac{c}{2}}\right)}$$

where

M_{dd} = **section** drag divergence Mach number, where $\frac{dC_d}{dM} = 0.1$

κ_a = technology factor

$\Lambda_{\frac{c}{2}}$ = sweep of mid-chord

$\frac{t}{c}$ = **section** thickness to chord ratio

C_l = **section** lift coefficient

Wing planform may divided into series of panels and wave drag contributions summed

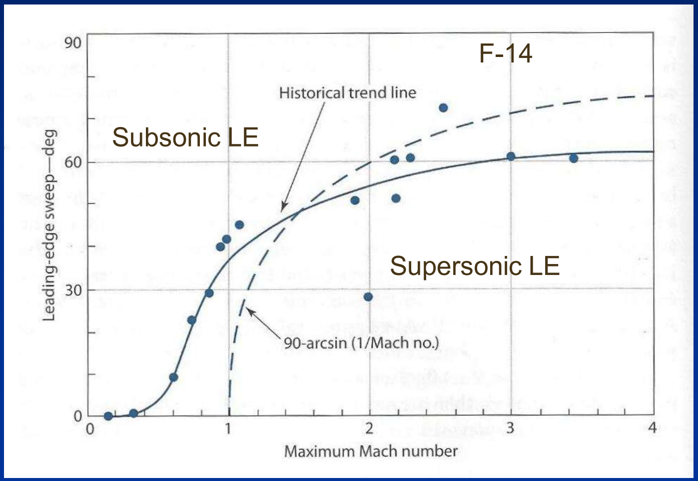
Source:: Gundlach Section 5.8.5

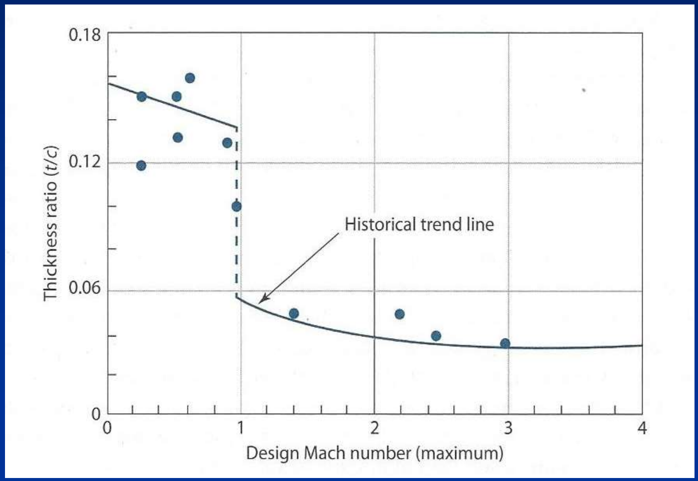
Typical Values of κ_a in Korn Equation

Wing or Aircraft	κ_a
NACA 6-series section*	0.87
Generic supercritical*	0.95

* Grasmeyer

LE Sweep and t/c Trend Lines





Source: Raymer

Winglet Design

Source: Aviation Week advertisement

- Take advantage of crossflows near wingtips due to tip vortices

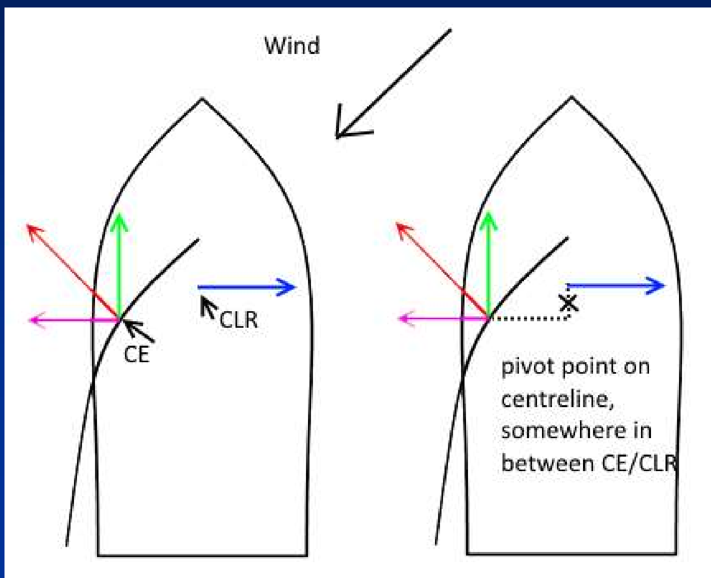
Winglet Design

https://aviation.stackexchange.com/questions/55992/why-do-i-see-moisture-coming-from-the-middle-of-the-wing-as-well-as-wingtip-vort

- Winglets appear to weaken tip vortices

ADAC Aircraft Design & Consulting

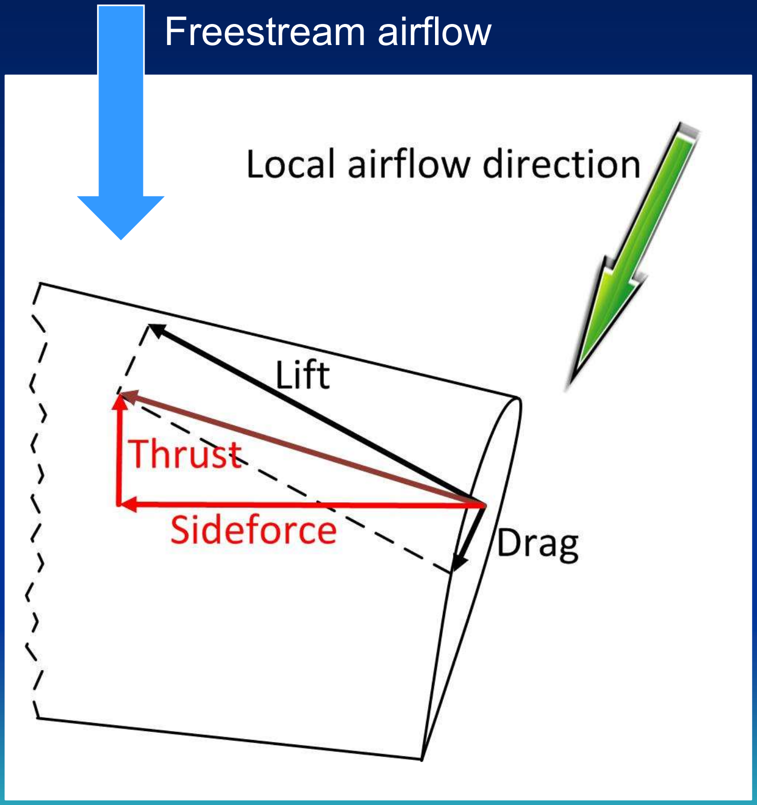
Winglet Action



- Similar to that of sailing boat sailing into the wind.

Plan View of Winglet

- Exaggerated inflow angle on upper surface
- Inflow angle is a function of wing C_L
- If winglet incidence is incorrect, then thrust may become drag



Winglet Installation on Existing Wing Design

- Smooth transition to minimize mutual interference
- Installation of B.757 winglet for UAL shown

Winglet Installation on 737 MAX

Source: www.boeing.com

- Integrated wingtip/winglet design can use smaller radius fillet

High Wing

- Advantages
  - Continuous wing upper surface (high L/D)
  - Clean propeller nacelle
  - Short airstairs
  - Easy baggage loading

High Wing

- Disadvantages
  - For jets, MLG on fuselage (more drag, narrow track)
  - For jets, landing wing inertia loads carried through wing root
  - Main spar passes through cabin
  - Pax view impaired

Source: John Wright

Low Wing

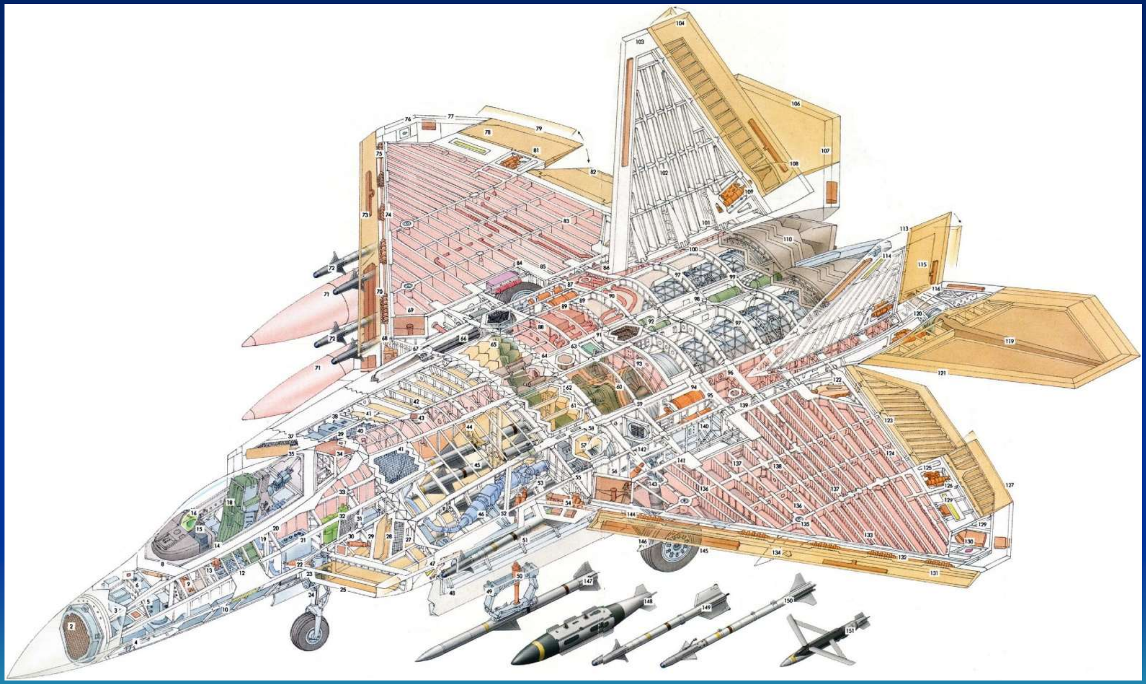
- Advantages
  - Wing box under cabin floor
  - Easier landing gear installation (esp. for large transport aircraft)
  - Good visibility for pax

Low Wing

- Disadvantages
  - Difficult to install high BPR engines under wing
  - Interference drag between wing and fuselage
  - Difficult to install airstairs

https://www.ndtv.com/world-news/boeing-says-its-open-to-changing-the-name-of-grounded-737-max-jet-2054867

F-22



https://conceptbunny.com/lockheed-martin-f-22-raptor/

https://retireenews.org/2016/10/25/f-22-raptor/

F-117

- Shield inlet and nozzle from ground-based missiles
- Minimize reflections from ground radar

F-35A

- Requirements for air superiority not as stringent as for F-22

Box Wing

- Advantages
  - Higher span efficiency
- Disadvantages
  - Difficult to integrate landing gear
  - Difficult to access passenger cabin
  - Insufficient wing volume for fuel

Lockheed Martin Box Wing concept

Joined Wing

- Advantages
  - Lighter structure
  - Good locations for multiple antennae
- Disadvantages
  - Must locate MLG in fuselage
  - Doesn't work well with long fuselage
  - Complex aerodynamics
  - Interference at wing join

A Boeing joined-wing, SensorCraft, undergoes testing at NASA Langley's 16 X 16-ft. wind tunnel in 2010.

Source: Aviation Week

Combined Box Wing/Joined Wing

- Advantages
  - Reduced interference at join
  - Good locations for multiple antennae
- Disadvantages
  - Need strong joint at bend of rear
  - Complex aerodynamics

The model in the foreground was prominently displayed at China's Zhuhai air show and provides a good view of the new UAV's unique planform.

Source: Aviation Week

Truss-Braced Wing (TBW)

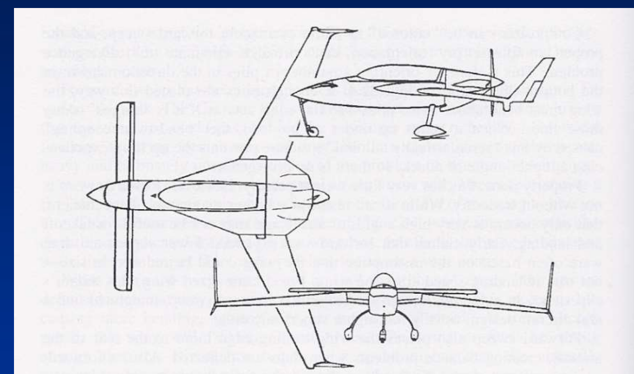
Source: Aviation Week

- 777-sized airplane
- High AR reduces induced drag
- Narrow chord promotes laminar flow
- Fuel burn reduction of 39% claimed

- Induced drag is only about 40% of total drag at high subsonic cruise
- Laminar flow is not a sure thing
- Must contend with strut interference drag

Canard Configuration

- Advantages
  - Both surfaces are lifting
  - Benign stalling characteristics
  - Canard can be used as active control surface



Rutan Vari-Eze

Source: Raymer

BAeTyphoon

Canard Configuration

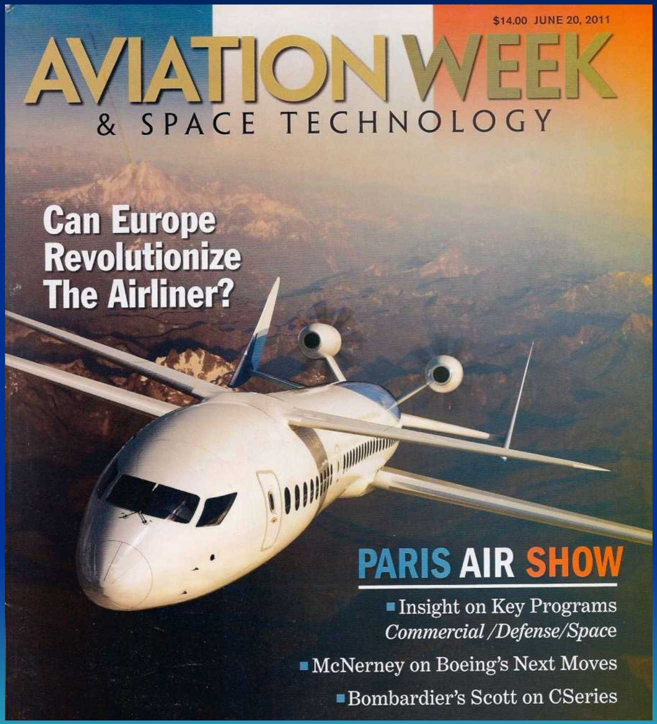
- Disadvantages
  - CG (and fuel tanks) forward of the wing
  - No wing root bending relief from fuel
  - More difficult to integrate landing gear
  - Larger nose-down pitching moment when flaps deployed
  - Non-uniform flow over wing
  - Shorter vertical stabilizer moment arm
  - May obscure pilot's view (see previous slide)

Source: rps3.com

Beech Starship

3-surface Configuration

- Airbus concept uses horizontal stabilizer to shield noise from unducted fan



Source: Aviation Week

3-surface Configuration

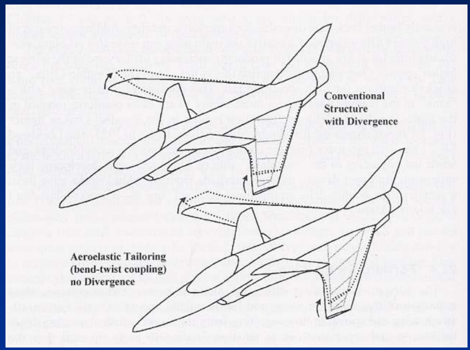
- Canard surface provides trim, aft surface provides control
- Advantages
  - Theoretical optimum spanwise lift distribution
  - Can put wing spar through middle of fuselage
- Disadvantages
  - More control surfaces implies greater maintenance
  - More difficult to integrate landing gear
  - Non-uniform flow over wing

Piaggio Avanti

Airbus UDF concept

Forward-swept Wing

- Advantages
  - Fast roll response
  - Avoids tip stall
  - In bizjet, can put wing spar through middle of fuselage
- Disadvantages
  - Root stall may cause pitchup
  - Needs structural tailoring to avoid divergence
  - Reduced efficiency of swept flaps



Source: Raymer

Source: www.hansajet.de

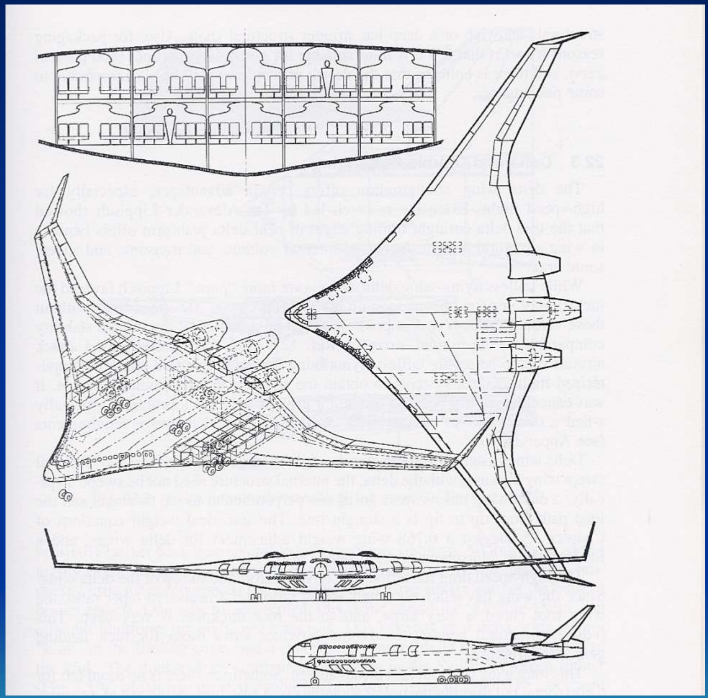
HFB-320 Hansa Jet

Blended Wing-Body

- Disadvantages (cont'd)
  - More difficult cargo loading and aircraft servicing
  - More difficult engine access
  - Excessive cabin motion when maneuvering
  - Difficult longitudinal trim (especially when using high-lift devices)
  - Non-uniform flow into engine nacelles at high α

Blended Wing-Body

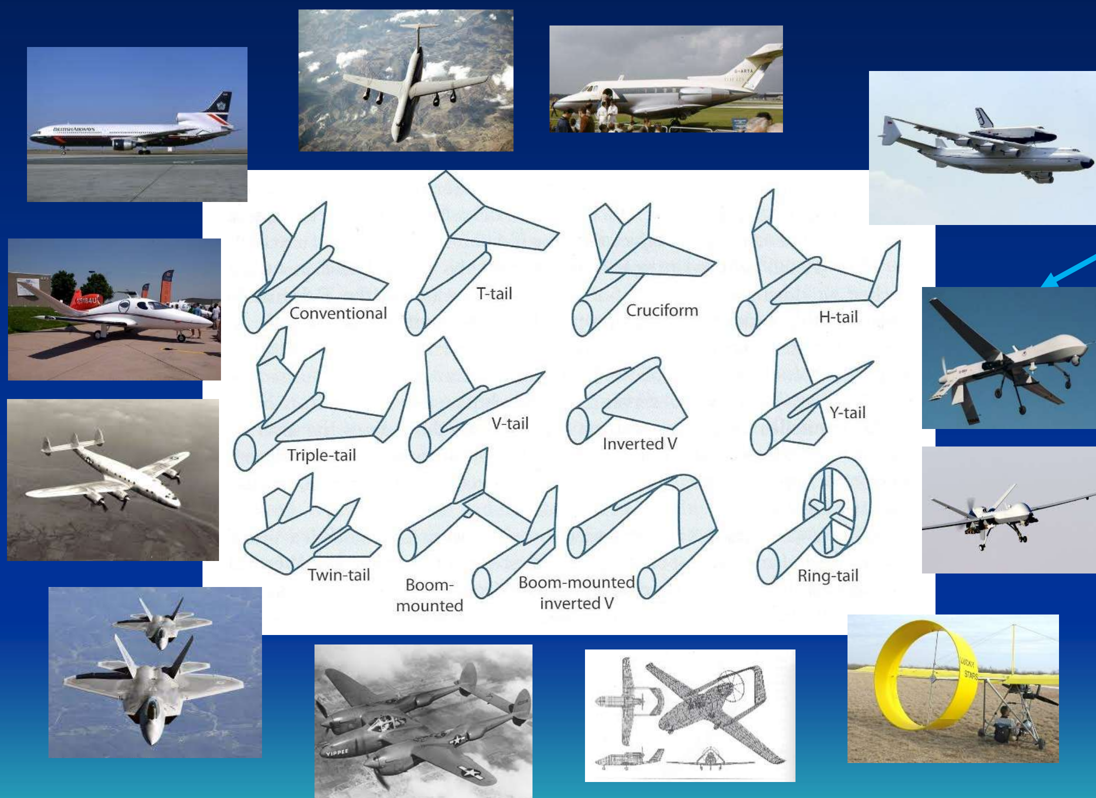
- Advantages
  - Higher L/D
  - Noise shielding of jet engines
- Disadvantages
  - Increased weight of non-cylindrical passenger cabin
  - Difficult passenger access/egress



Source: Raymer

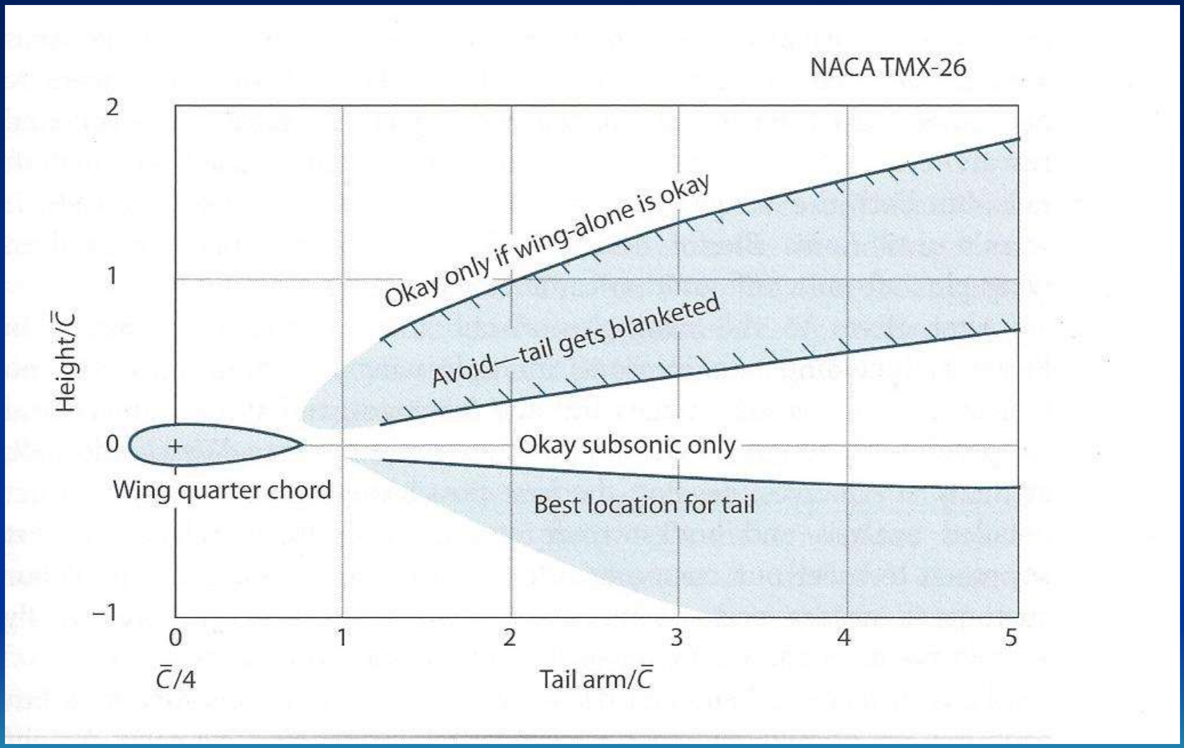
Section 4.5
Tail Geometry and Arrangement

Tail Layout Options



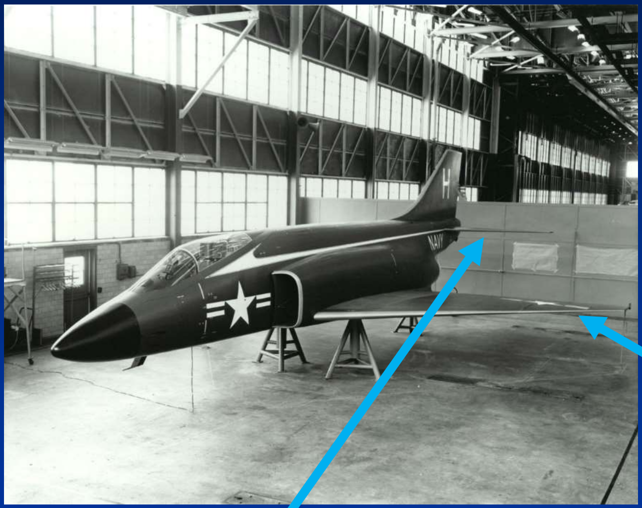
- Benefits of Inverted V or Y-tail
  - Offers appropriate stability and control
  - Clean air (not disturbed by wing or fuselage) over high range of α
  - Lightweight
  - Protects pusher propeller
  - Can get inside hangar

Preferred HT Location



Source: Raymer

McDonnell Douglas F-3H



Source: commons.Wikipedia.com

No anhedral on horizontal tail

No dihedral on outer wing panel

McDonnell Douglas F-4E

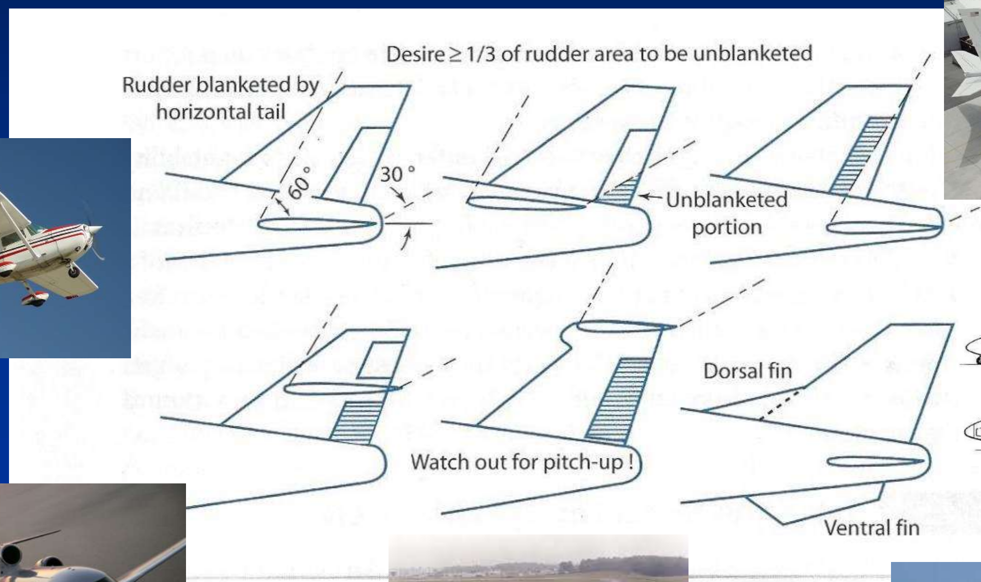
Source: commons.Wikipedia.com

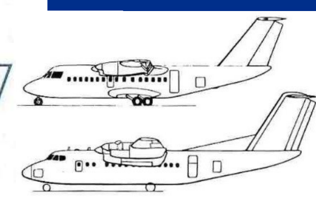
Avoids blanketing of tail at high α

Outer wing panel dihedral adds roll stability lost when setting anhedral on horizontal tail

ADAC Aircraft Design & Consulting

Tail Geometry for Spin Recovery





Source: Raymer

Twin Ventral Fins

"Learjet45-gama" by MilborneOne at English Wikipedia

- Nose-down pitching moment at stall
- Increased directional stability at high α

Inward Canted Vertical Fins

Source: urbanghostsmedia.com

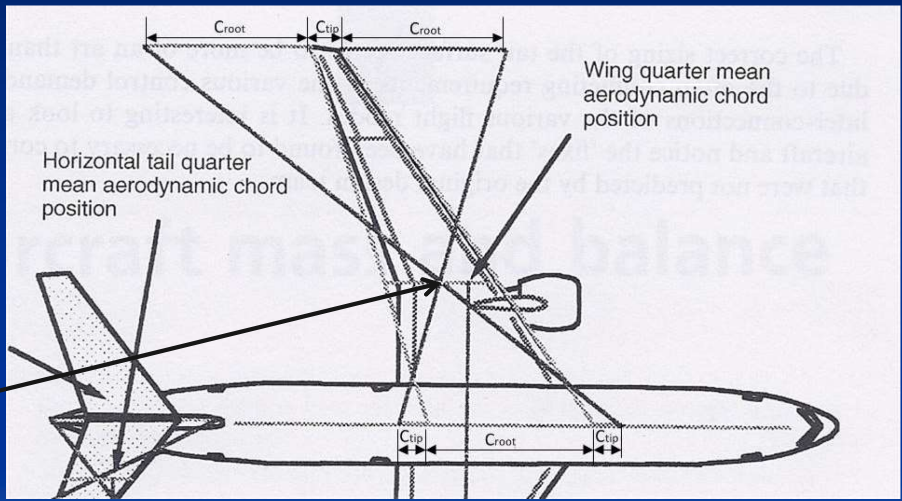
Lockheed Have Blue

- Gives partial shading of hot exhaust from heat-seeking missiles
- Eliminates corner reflector from vertical stabilizer

Preliminary Tail Sizing

An alternative method of graphically calculating the location of the MAC

1. Extend the tip chord forward and aft by the length of the wing root
2. Extend the root chord forward and aft by the length of the tip
3. Draw diagonals from the ends of the extended lines
4. Their intersection is the mid-chord of the MAC



Source: Jenkinson

Tail Volume Coefficients

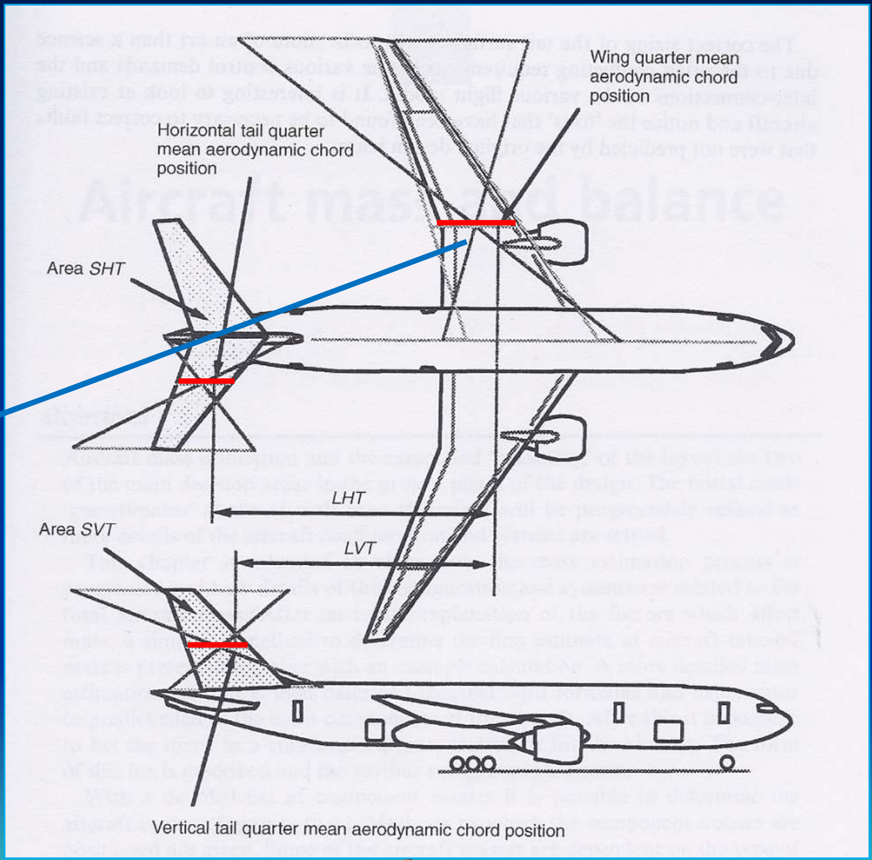
L_{HT} is distance from quarter chord of wing MAC to quarter chord of horizontal tail MAC
L_{VT} is distance from quarter chord of wing MAC to quarter chord of vertical tail MAC
b is wing span

Horizontal tail volume coefficient

$$\overline{V}_{HT} = \frac{L_{HT} S_{HT}}{\overline{c} S_{wing}}$$

Vertical tail volume coefficient

$$\overline{V}_{VT} = \frac{L_{VT} S_{VT}}{b S_{wing}}$$



Source: Jenkinson

Horizontal and Vertical Tail Volume Coefficients

Aircraft Category	V_{HT}	V_{VT}
Sailplane	0.50	0.02
Homebuilt	0.50	0.04
GA – single engine	0.70	0.04
GA – twin engine	0.80	0.07
Agricultural	0.50	0.04
Twin turboprop	0.90	0.08
Flying boat	0.70	0.06
Jet trainer	0.70	0.06
Jet fighter	0.40	0.07
Military cargo/bomber	1.00	0.08
Jet transport	1.00	0.09

Source: Raymer

Use these values for initial estimates. Tail areas will be determined by stability and control analysis

Where are we now?

- Have rough estimate of TOGW
- Have preliminary layout of airplane geometry
- Estimate of $(T/W)_{ref}$ and $(W/S)_{ref}$
- Hence thrust required and wing area
- Select AR, t/c, Λ, λ
- Estimate tail volumes

Airfoil and Wing/Tail Geometry Selection

The End